

Statistics Toolbox™

User's Guide

R2012b

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Revision History

September 1993	First printing	Version 1.0
March 1996	Second printing	Version 2.0
January 1997	Third printing	Version 2.11
November 2000	Fourth printing	Revised for Version 3.0 (Release 12)
May 2001	Fifth printing	Minor revisions
July 2002	Sixth printing	Revised for Version 4.0 (Release 13)
February 2003	Online only	Revised for Version 4.1 (Release 13.0.1)
June 2004	Seventh printing	Revised for Version 5.0 (Release 14)
October 2004	Online only	Revised for Version 5.0.1 (Release 14SP1)
March 2005	Online only	Revised for Version 5.0.2 (Release 14SP2)
September 2005	Online only	Revised for Version 5.1 (Release 14SP3)
March 2006	Online only	Revised for Version 5.2 (Release 2006a)
September 2006	Online only	Revised for Version 5.3 (Release 2006b)
March 2007	Eighth printing	Revised for Version 6.0 (Release 2007a)
September 2007	Ninth printing	Revised for Version 6.1 (Release 2007b)
March 2008	Online only	Revised for Version 6.2 (Release 2008a)
October 2008	Online only	Revised for Version 7.0 (Release 2008b)
March 2009	Online only	Revised for Version 7.1 (Release 2009a)
September 2009	Online only	Revised for Version 7.2 (Release 2009b)
March 2010	Online only	Revised for Version 7.3 (Release 2010a)
September 2010	Online only	Revised for Version 7.4 (Release 2010b)
April 2011	Online only	Revised for Version 7.5 (Release 2011a)
September 2011	Online only	Revised for Version 7.6 (Release 2011b)
March 2012	Online only	Revised for Version 8.0 (Release 2012a)
September 2012	Online only	Revised for Version 8.1 (Release 2012b)

Getting Started

1

Product Description	1-2
Key Features	1-2

Organizing Data

2

Introduction to Data Types	2-3
MATLAB Arrays	2-4
Numerical Data	2-4
Heterogeneous Data	2-7
Statistical Functions	2-9
Statistical Arrays	2-11
Introduction to Statistical Arrays	2-11
Categorical Data	2-13
Categorical Arrays	2-14
Nominal and Ordinal Variables	2-14
Using Categorical Arrays	2-15
Statistical Data	2-21
Dataset Arrays	2-22
Create Dataset Arrays	2-22
Create Categorical Arrays	2-24
Create Nominal Arrays	2-24
Create Ordinal Arrays	2-26
Change Category Labels	2-29
Reorder Category Levels	2-31

Reorder Category Levels in Ordinal Arrays	2-31
Reorder Category Levels in Nominal Arrays	2-32
Categorize Numeric Data	2-36
Merge Category Levels	2-39
Add and Drop Category Levels	2-41
Plot Data Grouped by Category	2-45
Test Differences Between Category Means	2-49
Summary Statistics Grouped by Category	2-58
Sort Ordinal Arrays	2-60
Categorical Arrays	2-62
What Are Categorical Arrays?	2-62
Categorical Array Conversion	2-62
Advantages of Using Categorical Arrays	2-64
Manipulate Category Levels	2-64
Analysis Using Categorical Arrays	2-64
Reduce Memory Requirements	2-65
Index and Search Using Categorical Arrays	2-67
Grouping Variables	2-72
What Are Grouping Variables?	2-72
Group Definition	2-73
Analysis Using Grouping Variables	2-73
Missing Group Values	2-74
Dummy Indicator Variables	2-76
What Are Dummy Variables?	2-76
Creating Dummy Variables	2-77

Regression with Categorical Covariates	2-80
Create a Dataset Array from Workspace Variables	2-86
Create a Dataset Array from a Numeric Array	2-86
Create Dataset Array from Heterogeneous Workspace Variables	2-89
Create a Dataset Array from a File	2-92
Create a Dataset Array from a Tab-Delimited Text File ..	2-92
Create a Dataset Array from a Comma-Separated Text File	2-95
Create a Dataset Array from an Excel File	2-98
Add and Delete Observations	2-100
Add and Delete Variables	2-104
Access Data in Dataset Array Variables	2-108
Select Subsets of Observations	2-114
Sort Observations in Dataset Arrays	2-118
Merge Dataset Arrays	2-122
Stack or Unstack Dataset Arrays	2-127
Calculations on Dataset Arrays	2-132
Export Dataset Arrays	2-136
Clean Messy and Missing Data	2-138
Dataset Arrays in the Variables Editor	2-143
Open Dataset Arrays in the Variables Editor	2-143
Modify Variable and Observation Names	2-144
Reorder or Delete Variables	2-146
Add New Data	2-148

Sort Observations	2-150
Select a Subset of Data	2-151
Create Plots	2-154
Dataset Arrays	2-156
What Are Dataset Arrays?	2-156
Dataset Array Conversion	2-156
Dataset Array Properties	2-157
Index and Search Dataset Arrays	2-159

Descriptive Statistics

3

Introduction to Descriptive Statistics	3-2
Measures of Central Tendency	3-3
Measures of Dispersion	3-5
Quantiles and Percentiles	3-7
Exploratory Analysis of Data	3-11
Resampling Statistics	3-16
Bootstrap	3-16
Jackknife	3-19
Parallel Computing Support for Resampling Methods	3-20
Data with Missing Values	3-21

Statistical Visualization

4

Introduction to Statistical Visualization	4-2
Scatter Plots	4-3
Box Plots	4-6
Distribution Plots	4-8
Normal Probability Plots	4-8
Quantile-Quantile Plots	4-10
Cumulative Distribution Plots	4-12
Other Probability Plots	4-14

Probability Distributions

5

Using Probability Distributions	5-2
Supported Distributions	5-3
Parametric Distributions	5-4
Nonparametric Distributions	5-9
Working with Distributions Through GUIs	5-10
Exploring Distributions	5-10
Modeling Data Using the Distribution Fitting Tool	5-12
Custom Distributions Using Distribution Fitting Tool	5-49
Visually Exploring Random Number Generation	5-50
Statistics Toolbox Distribution Functions	5-53
Probability Density Functions	5-53
Cumulative Distribution Functions	5-63
Inverse Cumulative Distribution Functions	5-67
Distribution Statistics Functions	5-69
Distribution Fitting Functions	5-71
Negative Log-Likelihood Functions	5-78

Random Number Generators	5-81
Using Probability Distribution Objects	5-85
Using Distribution Objects	5-85
What are Objects?	5-86
Creating Distribution Objects	5-89
Object-Supported Distributions	5-90
Performing Calculations Using Distribution Objects	5-91
Capturing Results Using Distribution Objects	5-98
Probability Distributions Used for Multivariate	
Modeling	5-100
Gaussian Mixture Models	5-100
Copulas: Generate Correlated Samples	5-108

Random Number Generation

6

Generating Random Data	6-2
Random Number Generation Functions	6-3
Common Generation Methods	6-5
Direct Methods	6-5
Inversion Methods	6-7
Acceptance-Rejection Methods	6-9
Representing Sampling Distributions Using Markov	
Chain Samplers	6-13
Using the Metropolis-Hastings Algorithm	6-13
Using Slice Sampling	6-14
Generating Quasi-Random Numbers	6-15
Quasi-Random Sequences	6-15
Quasi-Random Point Sets	6-16
Quasi-Random Streams	6-23

Generating Data Using Flexible Families of Distributions	6-25
Pearson and Johnson Systems	6-25
Generating Data Using the Pearson System	6-26
Generating Data Using the Johnson System	6-28

Hypothesis Tests

7

Introduction to Hypothesis Tests	7-2
Hypothesis Test Terminology	7-3
Hypothesis Test Assumptions	7-5
Hypothesis Testing	7-7
Available Hypothesis Tests	7-13

Analysis of Variance

8

Introduction to Analysis of Variance	8-2
ANOVA	8-3
One-Way ANOVA	8-3
Two-Way ANOVA	8-9
N-Way ANOVA	8-12
Other ANOVA Models	8-26
Analysis of Covariance	8-27
Nonparametric Methods	8-35
MANOVA	8-39
Introduction to MANOVA	8-39

Parametric Regression Analysis

9

Parametric Regression Analysis	9-2
What Is Parametric Regression?	9-2
Choose a Regression Function	9-2
Update Legacy Code with New Fitting Methods	9-3
Linear Regression	9-7
What Is a Linear Regression Model?	9-7
Prepare Data	9-8
Choose a Fitting Method	9-10
Choose a Model or Range of Models	9-11
Fit Model to Data	9-17
Examine Quality and Adjust the Fitted Model	9-17
Predict or Simulate Responses to New Data	9-36
Share Fitted Models	9-39
Linear Regression Workflow	9-40
Regression Using Dataset Arrays	9-47
Linear Regression with Interaction Effects	9-50
Interpret Linear Regression Results	9-60
Linear Regression Output and Diagnostic Statistics ..	9-68
Summary of Measures	9-68
Cook's Distance	9-69
Coefficient Confidence Intervals	9-72
Coefficient Covariance	9-74
Coefficient of Determination (R-Squared)	9-75
Delete-1 Change in Covariance (covratio)	9-78
Delete-1 Scaled Difference in Coefficient Estimates (Dfbetas)	9-81
Delete-1 Scaled Change in Fitted Values (Dffits)	9-83
Delete-1 Variance (S2_i)	9-85

Durbin-Watson Test	9-87
F-statistic	9-89
Hat Matrix	9-92
Leverage	9-93
Residuals	9-96
t-statistic	9-104
Stepwise Regression	9-108
Stepwise Regression to Select Appropriate Models	9-108
Compare large and small stepwise models	9-108
Robust Regression — Reduce Outlier Effects	9-113
What Is Robust Regression?	9-113
Robust Regression versus Standard Least-Squares Fit ...	9-113
Ridge Regression	9-116
Introduction to Ridge Regression	9-116
Ridge Regression	9-116
Lasso and Elastic Net	9-120
What Are Lasso and Elastic Net?	9-120
Lasso Regularization	9-120
Lasso and Elastic Net with Cross Validation	9-123
Wide Data via Lasso and Parallel Computing	9-126
Lasso and Elastic Net Details	9-131
References	9-133
Partial Least Squares	9-134
Introduction to Partial Least Squares	9-134
Partial Least Squares	9-135
Multivariate Regression	9-140
Generalized Linear Models	9-141
What Are Generalized Linear Models?	9-141
Prepare Data	9-142
Choose Generalized Linear Model and Link Function	9-144
Choose Fitting Method and Model	9-148
Fit Model to Data	9-153
Examine Quality and Adjust the Fitted Model	9-154
Predict or Simulate Responses to New Data	9-166

Share Fitted Models	9-169
Generalized Linear Model Workflow	9-171
Lasso Regularization of Generalized Linear Models ..	9-176
What is Generalized Linear Model Lasso	
Regularization?	9-176
Regularize Poisson Regression	9-176
Regularize Logistic Regression	9-180
Regularize Wide Data in Parallel	9-187
Generalized Linear Model Lasso and Elastic Net	9-193
References	9-195
Nonlinear Regression	9-196
What Are Parametric Nonlinear Regression Models?	9-196
Prepare Data	9-197
Represent the Nonlinear Model	9-198
Choose Initial Vector beta0	9-201
Fit Nonlinear Model to Data	9-201
Examine Quality and Adjust the Fitted Model	9-202
Predict or Simulate Responses to New Data	9-206
Nonlinear Regression Workflow	9-210
Mixed-Effects Models	9-217
Introduction to Mixed-Effects Models	9-217
Mixed-Effects Model Hierarchy	9-218
Specifying Mixed-Effects Models	9-219
Specifying Covariate Models	9-222
Choosing nlmeFit or nlmeFitsa	9-224
Using Output Functions with Mixed-Effects Models	9-227
Mixed-Effects Models Using nlmeFit and nlmeFitsa	9-232
Examining Residuals for Model Verification	9-247
Pitfalls in Fitting Nonlinear Models by Transforming to	
Linearity	9-253

Multivariate Methods

10

Introduction to Multivariate Methods	10-2
---	-------------

Multidimensional Scaling	10-3
Introduction to Multidimensional Scaling	10-3
Classical Multidimensional Scaling	10-3
Nonclassical Multidimensional Scaling	10-8
Nonmetric Multidimensional Scaling	10-10
Procrustes Analysis	10-14
Compare Landmark Data	10-14
Data Input	10-14
Preprocess Data for Accurate Results	10-15
Compare Handwritten Shapes	10-16
Feature Selection	10-23
Introduction to Feature Selection	10-23
Sequential Feature Selection	10-23
Feature Transformation	10-28
Introduction to Feature Transformation	10-28
Nonnegative Matrix Factorization	10-28
Principal Component Analysis (PCA)	10-31
Quality of Life in U.S. Cities	10-33
Factor Analysis	10-45
Partial Least Squares Regression and Principal Components Regression	10-55

Cluster Analysis

11

Introduction to Cluster Analysis	11-2
Hierarchical Clustering	11-3
Introduction to Hierarchical Clustering	11-3
Algorithm Description	11-3
Similarity Measures	11-4
Linkages	11-6
Dendrograms	11-8
Verify the Cluster Tree	11-10

Create Clusters	11-16
k-Means Clustering	11-21
Introduction to k-Means Clustering	11-21
Create Clusters and Determine Separation	11-22
Determine the Correct Number of Clusters	11-23
Avoid Local Minima	11-26
Gaussian Mixture Models	11-28
Introduction to Gaussian Mixture Models	11-28
Cluster with Gaussian Mixtures	11-28

Parametric Classification

12

Parametric Classification	12-2
Discriminant Analysis	12-3
What Is Discriminant Analysis?	12-3
Create Discriminant Analysis Classifiers	12-3
Creating a Classifier Using ClassificationDiscriminant.fit	12-4
How the predict Method Classifies	12-6
Create and Visualize a Discriminant Analysis Classifier ..	12-9
Improve a Discriminant Analysis Classifier	12-14
Regularize a Discriminant Analysis Classifier	12-22
Examine the Gaussian Mixture Assumption	12-29
Bibliography	12-35
Naive Bayes Classification	12-36
Supported Distributions	12-36
Performance Curves	12-39
Introduction to Performance Curves	12-39
What are ROC Curves?	12-39
Evaluate Classifier Performance Using perfcurve	12-39

Supervised Learning (Machine Learning) Workflow and Algorithms	13-2
Steps in Supervised Learning (Machine Learning)	13-2
Characteristics of Algorithms	13-7
Classification Using Nearest Neighbors	13-9
Pairwise Distance	13-9
<i>k</i> -Nearest Neighbor Search and Radius Search	13-12
<i>K</i> -Nearest Neighbor Classification for Supervised Learning	13-25
Construct a KNN Classifier	13-25
Examine the Quality of a KNN Classifier	13-26
Predict Classification Based on a KNN Classifier	13-27
Modify a KNN Classifier	13-27
Classification Trees and Regression Trees	13-30
What Are Classification Trees and Regression Trees?	13-30
Creating a Classification Tree	13-31
Creating a Regression Tree	13-31
Viewing a Tree	13-32
How the Fit Methods Create Trees	13-34
Predicting Responses With Classification and Regression Trees	13-36
Improving Classification Trees and Regression Trees	13-37
Alternative: classregtree	13-46
Ensemble Methods	13-54
Framework for Ensemble Learning	13-54
Basic Ensemble Examples	13-64
Test Ensemble Quality	13-66
Classification with Imbalanced Data	13-71
Classification: Imbalanced Data or Unequal Misclassification Costs	13-76
Classification with Many Categorical Levels	13-83
Surrogate Splits	13-88
LPBoost and TotalBoost for Small Ensembles	13-93
Ensemble Regularization	13-98
Tuning RobustBoost	13-110
Random Subspace Classification	13-114

TreeBagger Examples	13-120
Ensemble Algorithms	13-141
Bibliography	13-157

Markov Models

14

Introduction to Markov Models	14-2
Markov Chains	14-3
Hidden Markov Models (HMM)	14-5
Introduction to Hidden Markov Models (HMM)	14-5
Analyzing Hidden Markov Models	14-7

Design of Experiments

15

Design of Experiments	15-2
Full Factorial Designs	15-3
Multilevel Designs	15-3
Two-Level Designs	15-4
Fractional Factorial Designs	15-5
Introduction to Fractional Factorial Designs	15-5
Plackett-Burman Designs	15-5
General Fractional Designs	15-6
Response Surface Designs	15-9
Introduction to Response Surface Designs	15-9
Central Composite Designs	15-9
Box-Behnken Designs	15-13

D-Optimal Designs	15-15
Introduction to D-Optimal Designs	15-15
Generate D-Optimal Designs	15-16
Augment D-Optimal Designs	15-19
Specify Fixed Covariate Factors	15-20
Specify Categorical Factors	15-21
Specify Candidate Sets	15-21

Statistical Process Control

16

Introduction to Statistical Process Control	16-2
Control Charts	16-3
Capability Studies	16-6

Parallel Statistics

17

Quick Start Parallel Computing for Statistics	
Toolbox	17-2
What Is Parallel Statistics Functionality?	17-2
How To Compute in Parallel	17-3
Parallel Treebagger	17-5
 Concepts of Parallel Computing in Statistics	
Toolbox	17-7
Subtleties in Parallel Computing	17-7
Vocabulary for Parallel Computation	17-7
 When to Run Statistical Functions in Parallel	17-8
Why Run in Parallel?	17-8
Factors Affecting Speed	17-8
Factors Affecting Results	17-9

Working with parfor	17-10
How Statistical Functions Use parfor	17-10
Characteristics of parfor	17-11
Reproducibility in Parallel Statistical Computations ..	17-13
Issues and Considerations in Reproducing Parallel Computations	17-13
Running Reproducible Parallel Computations	17-14
Parallel Statistical Computation Using Random Numbers	17-15
Examples of Parallel Statistical Functions	17-19
Parallel Jackknife	17-19
Parallel Cross Validation	17-20
Parallel Bootstrap	17-21

Function Reference

18

File I/O	18-2
Data Organization	18-3
Categorical Arrays	18-3
Dataset Arrays	18-6
Grouped Data	18-8
Descriptive Statistics	18-9
Summaries	18-9
Measures of Central Tendency	18-9
Measures of Dispersion	18-9
Measures of Shape	18-10
Statistics Resampling	18-10
Data with Missing Values	18-10
Data Correlation	18-11
Statistical Visualization	18-12
Distribution Plots	18-12
Scatter Plots	18-13

ANOVA Plots	18-13
Regression Plots	18-14
Multivariate Plots	18-15
Cluster Plots	18-15
Classification Plots	18-16
DOE Plots	18-16
SPC Plots	18-16
Probability Distributions	18-17
Distribution Objects	18-17
Distribution Plots	18-18
Probability Density	18-19
Cumulative Distribution	18-21
Inverse Cumulative Distribution	18-23
Distribution Statistics	18-25
Distribution Fitting	18-26
Negative Log-Likelihood	18-28
Random Number Generators	18-28
Quasi-Random Numbers	18-30
Piecewise Distributions	18-31
Hypothesis Tests	18-33
Analysis of Variance	18-35
ANOVA Plots	18-35
ANOVA Operations	18-35
Parametric Regression Analysis	18-36
Regression Plots	18-36
Linear Regression	18-37
Generalized Linear Regression	18-39
Nonlinear Regression	18-40
Multivariate Methods	18-42
Multivariate Plots	18-42
Multidimensional Scaling	18-42
Procrustes Analysis	18-42
Feature Selection	18-43
Feature Transformation	18-43
Cluster Analysis	18-45

Cluster Plots	18-45
Hierarchical Clustering	18-45
K-Means Clustering	18-46
Gaussian Mixture Models	18-46
Model Assessment	18-47
Parametric Classification	18-48
Discriminant Analysis	18-48
Naive Bayes Classification	18-49
Classification Plots	18-50
Nonparametric Supervised Learning	18-51
Distance Computation and Classification by Distance	18-51
Classification Trees	18-52
Regression Trees	18-55
Ensemble Methods — Classification	18-58
Ensemble Methods — Regression	18-60
Hidden Markov Models	18-64
Design of Experiments	18-65
DOE Plots	18-65
Full Factorial Designs	18-65
Fractional Factorial Designs	18-66
Response Surface Designs	18-66
D-Optimal Designs	18-66
Latin Hypercube Designs	18-66
Quasi-Random Designs	18-67
Statistical Process Control	18-69
SPC Plots	18-69
SPC Functions	18-69
GUIs	18-70
Utilities	18-71

Data Organization	19-2
Categorical Arrays	19-2
Dataset Arrays	19-2
Probability Distributions	19-3
Distribution Objects	19-3
Quasi-Random Numbers	19-3
Piecewise Distributions	19-4
Gaussian Mixture Models	19-5
Model Assessment	19-6
Parametric Regression	19-7
Parametric Classification	19-8
Discriminant Analysis	19-8
Naive Bayes Classification	19-8
Supervised Learning	19-9
Distance Classifiers	19-9
Classification Trees	19-9
Classification Ensemble Classes	19-9
Regression Trees	19-10
Regression Ensemble Classes	19-10
Quasi-Random Design of Experiments	19-11

Sample Data Sets

A

Distribution Reference

B

Bernoulli Distribution	B-3
Definition of the Bernoulli Distribution	B-3
See Also	B-3
Beta Distribution	B-4
Definition	B-4
Background	B-4
Parameters	B-5
Example	B-6
See Also	B-6
Binomial Distribution	B-7
Definition	B-7
Background	B-7
Parameters	B-8
Example	B-9
See Also	B-9
Birnbaum-Saunders Distribution	B-10
Definition	B-10
Background	B-10
Parameters	B-11
See Also	B-11
Burr Type XII Distribution	B-12
Definition	B-12

Background	B-13
Parameters	B-14
Fit a Burr Distribution and Draw the cdf	B-15
Compare Lognormal and Burr pdfs	B-17
Burr pdf for Various Parameters	B-19
Survival and Hazard Functions of Burr Distribution	B-20
Divergence of Parameter Estimates	B-22
See Also	B-24
Chi-Square Distribution	B-25
Definition	B-25
Background	B-25
Example	B-26
See Also	B-26
Copulas	B-27
Custom Distributions	B-28
Exponential Distribution	B-29
Definition	B-29
Background	B-29
Parameters	B-29
Example	B-30
See Also	B-31
Extreme Value Distribution	B-32
Definition	B-32
Background	B-32
Parameters	B-34
Example	B-35
See Also	B-37
F Distribution	B-38
Definition	B-38
Background	B-38
Example	B-39
See Also	B-39
Gamma Distribution	B-40
Definition	B-40

Background	B-40
Parameters	B-41
Example	B-42
See Also	B-42
Gaussian Distribution	B-43
Gaussian Mixture Distributions	B-44
Generalized Extreme Value Distribution	B-45
Definition	B-45
Background	B-45
Parameters	B-46
Example	B-47
See Also	B-49
Generalized Pareto Distribution	B-50
Definition	B-50
Background	B-50
Parameters	B-51
Example	B-52
See Also	B-53
Geometric Distribution	B-54
Definition	B-54
Background	B-54
Example	B-54
See Also	B-55
Hypergeometric Distribution	B-56
Definition	B-56
Background	B-56
Example	B-57
See Also	B-57
Inverse Gaussian Distribution	B-58
Definition	B-58
Background	B-58
Parameters	B-58
See Also	B-58

Inverse Wishart Distribution	B-59
Definition	B-59
Background	B-59
Example	B-59
See Also	B-60
Johnson System	B-61
Logistic Distribution	B-62
Definition	B-62
Background	B-62
Parameters	B-62
See Also	B-62
Loglogistic Distribution	B-63
Definition	B-63
Parameters	B-63
See Also	B-63
Lognormal Distribution	B-64
Definition	B-64
Background	B-64
Example	B-65
See Also	B-66
Multinomial Distribution	B-67
Definition	B-67
Background	B-67
Example	B-67
See Also	B-69
Multivariate Gaussian Distribution	B-70
Multivariate Normal Distribution	B-71
Definition	B-71
Background	B-71
Example	B-72
See Also	B-76
Multivariate t Distribution	B-77

Definition	B-77
Background	B-77
Example	B-78
See Also	B-82
Nakagami Distribution	B-83
Definition	B-83
Background	B-83
Parameters	B-83
See Also	B-84
Negative Binomial Distribution	B-85
Definition	B-85
Background	B-85
Parameters	B-86
Example	B-87
See Also	B-88
Noncentral Chi-Square Distribution	B-89
Definition	B-89
Background	B-89
Example	B-90
See Also	B-90
Noncentral F Distribution	B-91
Definition	B-91
Background	B-91
Example	B-92
See Also	B-92
Noncentral t Distribution	B-93
Definition	B-93
Background	B-93
Example	B-94
See Also	B-94
Nonparametric Distributions	B-95
Normal Distribution	B-96
Definition	B-96
Background	B-96

Parameters	B-97
Example	B-98
See Also	B-98
Pareto Distribution	B-99
Pearson System	B-100
Piecewise Distributions	B-101
Poisson Distribution	B-102
Definition	B-102
Background	B-102
Parameters	B-103
Example	B-103
See Also	B-103
Rayleigh Distribution	B-104
Definition	B-104
Background	B-104
Parameters	B-105
Example	B-105
See Also	B-105
Rician Distribution	B-106
Definition	B-106
Background	B-106
Parameters	B-106
See Also	B-107
Student's t Distribution	B-108
Definition	B-108
Background	B-108
Example	B-109
See Also	B-109
t Location-Scale Distribution	B-110
Definition	B-110
Background	B-110
Parameters	B-110

See Also	B-111
Uniform Distribution (Continuous)	B-112
Definition	B-112
Background	B-112
Parameters	B-112
Example	B-112
See Also	B-113
Uniform Distribution (Discrete)	B-114
Definition	B-114
Background	B-114
Example	B-114
See Also	B-115
Weibull Distribution	B-116
Definition	B-116
Background	B-116
Parameters	B-117
Example	B-117
See Also	B-118
Wishart Distribution	B-119
Definition	B-119
Background	B-119
Example	B-120
See Also	B-120

Bibliography

C

Index

Getting Started

Product Description

Perform statistical modeling and analysis

Statistics Toolbox™ provides algorithms and tools for organizing, analyzing, and modeling data. You can use regression or classification for predictive modeling, generate random numbers for Monte Carlo simulations, use statistical plots for exploratory data analysis, and perform hypothesis tests.

For analyzing multidimensional data, Statistics Toolbox includes algorithms that let you identify key variables that impact your model with sequential feature selection, transform your data with principal component analysis, apply regularization and shrinkage, or use partial least-squares regression.

Statistics Toolbox includes specialized data types for organizing and accessing heterogeneous data. Dataset arrays store numeric data, text, and metadata in a single data container. Built-in methods enable you to merge datasets using a common key (join), calculate summary statistics on grouped data, and convert between tall and wide data representations. Categorical arrays provide a memory-efficient data container for storing information drawn from a finite, discrete set of categories.

Key Features

- Statistical arrays for storing heterogeneous and categorical data
- Regression techniques, including linear, nonlinear, robust, and ridge, and nonlinear mixed-effects models
- Classification algorithms, including boosted and bagged decision trees, k-Nearest Neighbor, and linear discriminant analysis
- Analysis of variance (ANOVA)
- Probability distributions, including copulas and Gaussian mixtures
- Random number generation
- Hypothesis testing
- Design of experiments and statistical process control

Organizing Data

- “Introduction to Data Types” on page 2-3
- “MATLAB Arrays” on page 2-4
- “Statistical Arrays” on page 2-11
- “Create Categorical Arrays” on page 2-24
- “Change Category Labels” on page 2-29
- “Reorder Category Levels” on page 2-31
- “Categorize Numeric Data” on page 2-36
- “Merge Category Levels” on page 2-39
- “Add and Drop Category Levels” on page 2-41
- “Plot Data Grouped by Category” on page 2-45
- “Test Differences Between Category Means” on page 2-49
- “Summary Statistics Grouped by Category” on page 2-58
- “Sort Ordinal Arrays” on page 2-60
- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64
- “Index and Search Using Categorical Arrays” on page 2-67
- “Grouping Variables” on page 2-72
- “Dummy Indicator Variables” on page 2-76
- “Regression with Categorical Covariates” on page 2-80
- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Create a Dataset Array from a File” on page 2-92

- “Add and Delete Observations” on page 2-100
- “Add and Delete Variables” on page 2-104
- “Access Data in Dataset Array Variables” on page 2-108
- “Select Subsets of Observations” on page 2-114
- “Sort Observations in Dataset Arrays” on page 2-118
- “Merge Dataset Arrays” on page 2-122
- “Stack or Unstack Dataset Arrays” on page 2-127
- “Calculations on Dataset Arrays” on page 2-132
- “Export Dataset Arrays” on page 2-136
- “Clean Messy and Missing Data” on page 2-138
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Dataset Arrays” on page 2-156
- “Index and Search Dataset Arrays” on page 2-159

Introduction to Data Types

MATLAB® data is placed into “data containers” in the form of workspace variables. All workspace variables organize data into some form of array. For statistical purposes, arrays are viewed as tables of values.

MATLAB variables use different structures to organize data:

- 2-D numerical arrays (matrices) organize observations and measured variables by rows and columns, respectively.
- Multidimensional arrays organize multidimensional observations or experimental designs.
- Cell and structure arrays organize heterogeneous data of different types, sizes, units, etc.

Data types determine the kind of data variables contain.

These basic MATLAB container variables are reviewed, in a statistical context, in the section on “MATLAB Arrays” on page 2-4.

These variables are not specifically designed for statistical data, however. Statistical data generally involves observations of multiple variables, with measurements of heterogeneous type and size. Data may be numerical (of type `single` or `double`), categorical, or in the form of descriptive metadata. Fitting statistical data into basic MATLAB variables, and accessing it efficiently, can be cumbersome.

Statistics Toolbox software offers two additional types of container variables specifically designed for statistical data:

- Categorical arrays accommodate data in the form of discrete levels, together with its descriptive metadata.
- Dataset arrays encapsulate heterogeneous data and metadata, including categorical data, which is accessed and manipulated using familiar methods analogous to those for numerical matrices.

These statistical container variables are discussed in the section on “Statistical Arrays” on page 2-11.

MATLAB Arrays

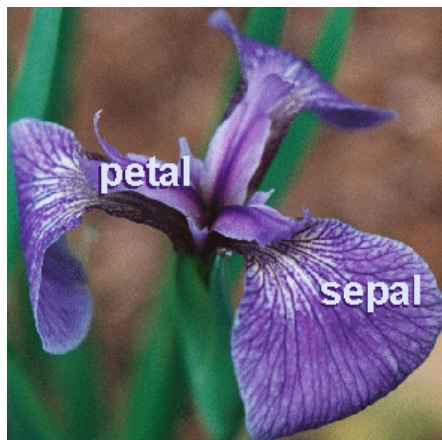
In this section...
“Numerical Data” on page 2-4
“Heterogeneous Data” on page 2-7
“Statistical Functions” on page 2-9

Numerical Data

MATLAB two-dimensional numerical arrays (matrices) containing statistical data use rows to represent observations and columns to represent measured variables. For example,

```
load fisheriris % Fisher's iris data (1936)
```

loads the variables `meas` and `species` into the MATLAB workspace. The `meas` variable is a 150-by-4 numerical matrix, representing 150 observations of 4 different measured variables (by column: sepal length, sepal width, petal length, and petal width, respectively).



The observations in `meas` are of three different species of iris (*setosa*, *versicolor*, and *virginica*), which can be separated from one another using the 150-by-1 cell array of strings `species`:

```
setosa_indices = strcmp('setosa',species);
setosa = meas(setosa_indices,:);
```

The resulting `setosa` variable is 50-by-4, representing 50 observations of the 4 measured variables for iris setosa.

To access and display the first five observations in the `setosa` data, use row, column parenthesis indexing:

```
SetosaObs = setosa(1:5,:);
SetosaObs =
    5.1000    3.5000    1.4000    0.2000
    4.9000    3.0000    1.4000    0.2000
    4.7000    3.2000    1.3000    0.2000
    4.6000    3.1000    1.5000    0.2000
    5.0000    3.6000    1.4000    0.2000
```

The data are organized into a table with implicit column headers “Sepal Length,” “Sepal Width,” “Petal Length,” and “Petal Width.” Implicit row headers are “Observation 1,” “Observation 2,” “Observation 3,” etc.

Similarly, 50 observations for iris versicolor and iris virginica can be extracted from the `meas` container variable:

```
versicolor_indices = strcmp('versicolor',species);
versicolor = meas(versicolor_indices,:);

virginica_indices = strcmp('virginica',species);
virginica = meas(virginica_indices,:);
```

Because the data sets for the three species happen to be of the same size, they can be reorganized into a single 50-by-4-by-3 multidimensional array:

```
iris = cat(3,setosa,versicolor,virginica);
```

The `iris` array is a three-layer table with the same implicit row and column headers as the `setosa`, `versicolor`, and `virginica` arrays. The implicit layer names, along the third dimension, are “Setosa,” “Versicolor,” and “Virginica.” The utility of such a multidimensional organization depends on assigning meaningful properties of the data to each dimension.

To access and display data in a multidimensional array, use parenthesis indexing, as for 2-D arrays. The following gives the first five observations of sepal lengths in the setosa data:

```
SetosaSL = iris(1:5,1,1)
SetosaSL =
    5.1000
    4.9000
    4.7000
    4.6000
    5.0000
```

Multidimensional arrays provide a natural way to organize numerical data for which the observations, or experimental designs, have many dimensions. If, for example, data with the structure of `iris` are collected by multiple observers, in multiple locations, over multiple dates, the entirety of the data can be organized into a single higher dimensional array with dimensions for “Observer,” “Location,” and “Date.” Likewise, an experimental design calling for m observations of n p -dimensional variables could be stored in an m -by- n -by- p array.

Numerical arrays have limitations when organizing more general statistical data. One limitation is the implicit nature of the metadata. Another is the requirement that multidimensional data be of commensurate size across all dimensions. If variables have different lengths, or the number of variables differs by layer, then multidimensional arrays must be artificially padded with NaNs to indicate “missing values.” These limitations are addressed by dataset arrays, which are specifically designed for statistical data.

Heterogeneous Data

MATLAB data types include two container variables—cell arrays and structure arrays—that allow you to combine metadata with variables of different types and sizes.

The data in the variables `setosa`, `versicolor`, and `virginica` created in “Numerical Data” on page 2-4 can be organized in a cell array, as follows:

```
iris1 = cell(51,5,3); % Container variable

obsnames = strcat({'Obs'},num2str((1:50)', '%-d'));
iris1(2:end,1,:) = repmat(obsnames,[1 1 3]);

varnames = {'SepalLength', 'SepalWidth', ...
            'PetalLength', 'PetalWidth'};
iris1(1,2:end,:) = repmat(varnames,[1 1 3]);

iris1(2:end,2:end,1) = num2cell(setosa);
iris1(2:end,2:end,2) = num2cell(versicolor);
iris1(2:end,2:end,3) = num2cell(virginica);

iris1{1,1,1} = 'Setosa';
iris1{1,1,2} = 'Versicolor';
iris1{1,1,3} = 'Virginica';
```

To access and display the cells, use parenthesis indexing. The following displays the first five observations in the `setosa` sepal data:

```
SetosaSLSW = iris1(1:6,1:3,1)
SetosaSLSW =
    'Setosa'    'SepalLength'    'SepalWidth'
    'Obs1'     [    5.1000]     [    3.5000]
    'Obs2'     [    4.9000]     [         3]
    'Obs3'     [    4.7000]     [    3.2000]
    'Obs4'     [    4.6000]     [    3.1000]
    'Obs5'     [         5]     [    3.6000]
```

Here, the row and column headers have been explicitly labeled with metadata.

To extract the data subset, use row, column curly brace indexing:

```
subset = reshape([iris1{2:6,2:3,1}],5,2)
subset =
    5.1000    3.5000
    4.9000    3.0000
    4.7000    3.2000
    4.6000    3.1000
    5.0000    3.6000
```

While cell arrays are useful for organizing heterogeneous data, they may be cumbersome when it comes to manipulating and analyzing the data. MATLAB and Statistics Toolbox statistical functions do not accept data in the form of cell arrays. For processing, data must be extracted from the cell array to a numerical container variable, as in the preceding example. The indexing can become complicated for large, heterogeneous data sets. This limitation of cell arrays is addressed by dataset arrays, which are designed to store general statistical data and provide easy access.

The data in the preceding example can also be organized in a structure array, as follows:

```
iris2.data = cat(3,setosa,versicolor,virginica);
iris2.varnames = {'SepalLength','SepalWidth',...
                'PetalLength','PetalWidth'};
iris2.obsnames = strcat({'Obs'},num2str((1:50)','%-d'));
iris2.species = {'setosa','versicolor','virginica'};
```

The data subset is then returned using a combination of dot and parenthesis indexing:

```
subset = iris2.data(1:5,1:2,1)
subset =
    5.1000    3.5000
    4.9000    3.0000
    4.7000    3.2000
    4.6000    3.1000
    5.0000    3.6000
```

For statistical data, structure arrays have many of the same limitations as cell arrays. Once again, dataset arrays, designed specifically for general statistical data, address these limitations.

Statistical Functions

One of the advantages of working in the MATLAB language is that functions operate on entire arrays of data, not just on single scalar values. The functions are said to be *vectorized*. Vectorization allows for both efficient problem formulation, using array-based data, and efficient computation, using vectorized statistical functions.

When MATLAB and Statistics Toolbox statistical functions operate on a vector of numerical data (either a row vector or a column vector), they return a single computed statistic:

```
% Fisher's setosa data:
load fisheriris
setosa_indices = strcmp('setosa',species);
setosa = meas(setosa_indices,:);

% Single variable from the data:
setosa_sepal_length = setosa(:,1);

% Standard deviation of the variable:
std(setosa_sepal_length)
ans =
    0.3525
```

When statistical functions operate on a matrix of numerical data, they treat the columns independently, as separate measured variables, and return a vector of statistics—one for each variable:

```
std(setosa)
ans =
    0.3525    0.3791    0.1737    0.1054
```

The four standard deviations are for measurements of sepal length, sepal width, petal length, and petal width, respectively.

Compare this to

```
std(setosa(:))
ans =
    1.8483
```

which gives the standard deviation across the entire array (all measurements).

Compare the preceding statistical calculations to the more generic mathematical operation

```
sin(setosa)
```

This operation returns a 50-by-4 array the same size as `setosa`. The `sin` function is vectorized in a different way than the `std` function, computing one scalar value for each element in the array.

MATLAB and Statistics Toolbox statistical functions, like `std`, must be distinguished from general mathematical functions like `sin`. Both are vectorized, and both are useful for working with array-based data, but only statistical functions summarize data across observations (rows) while preserving variables (columns). This property of statistical functions may be explicit, as with `std`, or implicit, as with `regress`. To see how a particular function handles array-based data, consult its reference page.

MATLAB statistical functions expect data input arguments to be in the form of numerical arrays. If data is stored in a cell or structure array, it must be extracted to a numerical array, via indexing, for processing. Statistics Toolbox functions are more flexible. Many toolbox functions accept data input arguments in the form of both numerical arrays and dataset arrays, which are specifically designed for storing general statistical data.

Statistical Arrays

In this section...

“Introduction to Statistical Arrays” on page 2-11

“Categorical Data” on page 2-13

“Categorical Arrays” on page 2-14

“Nominal and Ordinal Variables” on page 2-14

“Using Categorical Arrays” on page 2-15

“Statistical Data” on page 2-21

“Dataset Arrays” on page 2-22

“Create Dataset Arrays” on page 2-22

Introduction to Statistical Arrays

As discussed in “MATLAB Arrays” on page 2-4, MATLAB data types include arrays for numerical, logical, and character data, as well as cell and structure arrays for heterogeneous collections of data.

Statistics Toolbox software offers two additional types of arrays specifically designed for statistical data:

- categorical arrays
- dataset arrays

Categorical arrays store data with values in a discrete set of levels. Each level is meant to capture a single, defining characteristic of an observation. If no ordering is encoded in the levels, the data and the array are *nominal*. If an ordering is encoded, the data and the array are *ordinal*.

Categorical arrays also store labels for the levels. Nominal labels typically suggest the type of an observation, while ordinal labels suggest the position or rank.

Dataset arrays collect heterogeneous statistical data and metadata, including categorical data, into a single container variable. Like the numerical matrices

discussed in “Numerical Data” on page 2-4, dataset arrays can be viewed as tables of values, with rows representing different observations and columns representing different measured variables. Like the cell and structure arrays discussed in “Heterogeneous Data” on page 2-7, dataset arrays can accommodate variables of different types, sizes, units, etc.

Dataset arrays combine the organizational advantages of these basic MATLAB data types while addressing their shortcomings with respect to storing complex statistical data.

Both categorical and dataset arrays have associated methods for assembling, accessing, manipulating, and processing the collected data. Basic array operations parallel those for numerical, cell, and structure arrays.

Categorical Data

Categorical data take on values from only a finite, discrete set of categories or *levels*. Levels may be determined before the data are collected, based on the application, or they may be determined by the distinct values in the data when converting them to categorical form. Predetermined levels, such as a set of states or numerical intervals, are independent of the data they contain. Any number of values in the data may attain a given level, or no data at all. Categorical data show which measured values share common levels, and which do not.

Levels may have associated *labels*. Labels typically express a defining characteristic of an observation, captured by its level.

If no ordering is encoded in the levels, the data are *nominal*. Nominal labels typically indicate the type of an observation. Examples of nominal labels are {false, true}, {male, female}, and {Afghanistan, ..., Zimbabwe}. For nominal data, the numeric or lexicographic order of the labels is irrelevant—Afghanistan is not considered to be less than, equal to, or greater than Zimbabwe.

If an ordering is encoded in the levels—for example, if levels labeled “red”, “green”, and “blue” represent wavelengths—the data are *ordinal*. Labels for ordinal levels typically indicate the position or rank of an observation. Examples of ordinal labels are {0, 1}, {mm, cm, m, km}, and {poor, satisfactory, outstanding}. The ordering of the levels may or may not correspond to the numeric or lexicographic order of the labels.

Categorical Arrays

Categorical data can be represented using MATLAB integer arrays, but this method has a number of drawbacks. First, it removes all of the useful metadata that might be captured in labels for the levels. Labels must be stored separately, in character arrays or cell arrays of strings. Secondly, this method suggests that values stored in the integer array have their usual numeric meaning, which, for categorical data, they may not. Finally, integer types have a fixed set of levels (for example, `-128:127` for all `int8` arrays), which cannot be changed.

Categorical arrays, available in Statistics Toolbox software, are specifically designed for storing, manipulating, and processing categorical data and metadata. Unlike integer arrays, each categorical array has its own set of levels, which can be changed. Categorical arrays also accommodate labels for levels in a natural way. Like numerical arrays, categorical arrays take on different shapes and sizes, from scalars to N -D arrays.

Organizing data in a categorical array can be an end in itself. Often, however, categorical arrays are used for further statistical processing. They can be used to index into other variables, creating subsets of data based on the category of observation, or they can be used with statistical functions that accept categorical inputs.

Nominal and Ordinal Variables

Categorical arrays come in two types, depending on whether the collected data is understood to be nominal or ordinal. Nominal arrays are constructed with `nominal`; ordinal arrays are constructed with `ordinal`. For example,

```
load fisheriris
ndata = nominal(species,{'A','B','C'});
```

creates a nominal array with levels A, B, and C from the species data in `fisheriris.mat`, while

```
odata = ordinal(ndata,{},{'C','A','B'});
```

encodes an ordering of the levels with $C < A < B$. See “Using Categorical Arrays” on page 2-15, and the reference pages for `nominal` and `ordinal`, for further examples.

Categorical arrays are implemented as objects of the `categorical` class. The class is abstract, defining properties and methods common to both the `nominal` class and `ordinal` class. Use the corresponding constructors, `nominal` or `ordinal`, to create categorical arrays. Methods of the classes are used to display, summarize, convert, concatenate, and access the collected data. Many of these methods are invoked using operations analogous to those for numerical arrays, and do not need to be called directly (for example, `[]` invokes `horzcat`). Other methods, such as `reorderlevels`, must be called directly.

Using Categorical Arrays

This section provides an extended tutorial example demonstrating the use of categorical arrays with methods of the `nominal` class and `ordinal` class.

- “Constructing Categorical Arrays” on page 2-15
- “Accessing Categorical Arrays” on page 2-17
- “Combining Categorical Arrays” on page 2-18
- “Computing with Categorical Arrays” on page 2-20

Constructing Categorical Arrays

- 1** Load the 150-by-4 numerical array `meas` and the 150-by-1 cell array of strings `species`:

```
load fisheriris % Fisher's iris data (1936)
```

The data are 150 observations of four measured variables (by column number: sepal length, sepal width, petal length, and petal width, respectively) over three species of iris (`setosa`, `versicolor`, and `virginica`).

- 2** Use `nominal` to create a nominal array from `species`:

```
n1 = nominal(species);
```

- 3** Open `species` and `n1` side by side in the Variable Editor (see “View, Edit, and Copy Variables” in the MATLAB documentation). Note that the string information in `species` has been converted to categorical form, leaving

only information on which data share the same values, indicated by the labels for the levels.

By default, levels are labeled with the distinct values in the data (in this case, the strings in `species`). Give alternate labels with additional input arguments to the nominal constructor:

```
n2 = nominal(species,{'species1','species2','species3'});
```

- 4 Open `n2` in the Variable Editor, and compare it with `species` and `n1`. The levels have been relabeled.
- 5 Suppose that the data are considered to be ordinal. A characteristic of the data that is not reflected in the labels is the diploid chromosome count, which orders the levels corresponding to the three species as follows:

```
species1 < species3 < species2
```

Use `ordinal` to cast `n2` as an ordinal array:

```
o1 = ordinal(n2,{},{'species1','species3','species2'});
```

The second input argument to `ordinal` is the same as for `nominal`—a list of labels for the levels in the data. If it is unspecified, as above, the labels are inherited from the data, in this case `n2`. The third input argument of `ordinal` indicates the ordering of the levels, in ascending order.

- 6 When displayed side by side in the Variable Editor, `o1` does not appear any different than `n2`. This is because the data in `o1` have not been sorted. It is important to recognize the difference between the ordering of the levels in an ordinal array and sorting the actual data according to that ordering. Use `sort` to sort ordinal data in ascending order:

```
o2 = sort(o1);
```

When displayed in the Variable Editor, `o2` shows the data sorted by diploid chromosome count.

- 7 To find which elements moved up in the sort, use the `<` operator for ordinal arrays:

```
moved_up = (o1 < o2);
```


The operation returns a logical array `moved_up`, indicating which elements have moved up (the data for `species3`).

- 8 Use `getlabels` to display the labels for the levels in ascending order:

```
labels2 = getlabels(o2)
labels2 =
    'species1'    'species3'    'species2'
```

- 9 The `sort` function reorders the display of the data, but not the order of the levels. To reorder the levels, use `reorderlevels`:

```
o3 = reorderlevels(o2,labels2([1 3 2]));
labels3 = getlabels(o3)
labels3 =
    'species1'    'species2'    'species3'
o4 = sort(o3);
```

These operations return the levels in the data to their original ordering, by species number, and then sort the data for display purposes.

Accessing Categorical Arrays

Categorical arrays are accessed using parenthesis indexing, with syntax that parallels similar operations for numerical arrays (see “Numerical Data” on page 2-4).

Parenthesis indexing on the right-hand side of an assignment is used to extract the lowest 50 elements from the ordinal array `o4`:

```
low50 = o4(1:50);
```

Suppose you want to categorize the data in `o4` with only two levels: `low` (the data in `low50`) and `high` (the rest of the data). One way to do this is to use an assignment with parenthesis indexing on the left-hand side:

```
o5 = o4; % Copy o4
o5(1:50) = 'low';
Warning: Categorical level 'low' being added.
o5(51:end) = 'high';
Warning: Categorical level 'high' being added.
```

Note the warnings: the assignments move data to new levels. The old levels, though empty, remain:

```
getlabels(o5)
ans =
    'species1' 'species2' 'species3' 'low' 'high'
```

The old levels are removed using `droplevels`:

```
o5 = droplevels(o5,{'species1','species2','species3'});
```

Another approach to creating two categories in `o5` from the three categories in `o4` is to merge levels, using `mergelevels`:

```
o5 = mergelevels(o4,{'species1'},'low');
o5 = mergelevels(o5,{'species2','species3'},'high');
```

```
getlabels(o5)
ans =
    'low'      'high'
```

The merged levels are removed and replaced with the new levels.

Combining Categorical Arrays

Categorical arrays are concatenated using square brackets. Again, the syntax parallels similar operations for numerical arrays (see “Numerical Data” on page 2-4). There are, however, restrictions:

- Only categorical arrays of the same type can be combined. You cannot concatenate a nominal array with an ordinal array.
- Only ordinal arrays with the same levels, in the same order, can be combined.
- Nominal arrays with different levels can be combined to produce a nominal array whose levels are the union of the levels in the component arrays.

First use `ordinal` to create ordinal arrays from the variables for sepal length and sepal width in `meas`. Categorize the data as `short` or `long` depending on whether they are below or above the median of the variable, respectively:

```
s1 = meas(:,1); % Sepal length data
```

```

sw = meas(:,2); % Sepal width data
SL1 = ordinal(s1,{'short','long'},[],...
             [min(s1),median(s1),max(s1)]);
SW1 = ordinal(sw,{'short','long'},[],...
             [min(sw),median(sw),max(sw)]);

```

Because SL1 and SW1 are ordinal arrays with the same levels, in the same order, they can be concatenated:

```

S1 = [SL1,SW1];
S1(1:10,:)
ans =
    short      long
    short      long
    short      long
    short      long
    short      long
    short      long
    short      long
    short      long
    short      short
    short      long

```

The result is an ordinal array S1 with two columns.

If, on the other hand, the measurements are cast as nominal, different levels can be used for the different variables, and the two nominal arrays can still be combined:

```

SL2 = nominal(s1,{'short','long'},[],...
             [min(s1),median(s1),max(s1)]);
SW2 = nominal(sw,{'skinny','wide'},[],...
             [min(sw),median(sw),max(sw)]);
S2 = [SL2,SW2];
getlabels(S2)
ans =
    'short' 'long' 'skinny' 'wide'
S2(1:10,:)
ans =
    short      wide
    short      wide

```

```
short    wide
short    wide
short    wide
short    wide
short    wide
short    wide
short    skinny
short    wide
```

Computing with Categorical Arrays

Categorical arrays are used to index into other variables, creating subsets of data based on the category of observation, and they are used with statistical functions that accept categorical inputs.

Use `ismember` to create logical variables based on the category of observation. For example, the following creates a logical index the same size as `species` that is true for observations of iris setosa and false elsewhere. Recall that `n1 = nominal(species)`:

```
SetosaObs = ismember(n1, 'setosa');
```

Since the code above compares elements of `n1` to a single value, the same operation is carried out by the equality operator:

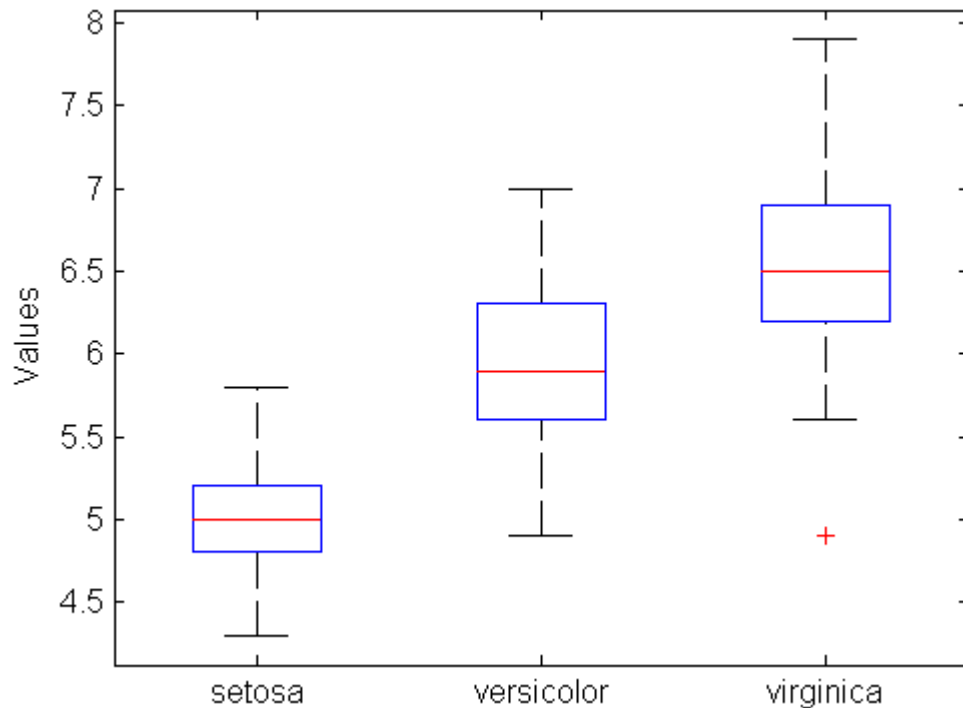
```
SetosaObs = (n1 == 'setosa');
```

The `SetosaObs` variable is used to index into `meas` to extract only the setosa data:

```
SetosaData = meas(SetosaObs, :);
```

Categorical arrays are also used as grouping variables. The following plot summarizes the sepal length data in `meas` by category:

```
boxplot(s1, n1)
```



Statistical Data

MATLAB data containers (variables) are suitable for completely homogeneous data (numeric, character, and logical arrays) and for completely heterogeneous data (cell and structure arrays). Statistical data, however, are often a mixture of homogeneous variables of heterogeneous types and sizes. Dataset arrays are suitable containers for this kind of data.

Dataset arrays can be viewed as tables of values, with rows representing different observations or cases and columns representing different measured variables. In this sense, dataset arrays are analogous to the numerical arrays for statistical data discussed in “Numerical Data” on page 2-4. Basic methods for creating and manipulating dataset arrays parallel the syntax of corresponding methods for numerical arrays.

While each column of a dataset array must be a variable of a single type, each row may contain an observation consisting of measurements of different

types. In this sense, dataset arrays lie somewhere between variables that enforce complete homogeneity on the data and those that enforce nothing. Because of the potentially heterogeneous nature of the data, dataset arrays have indexing methods with syntax that parallels corresponding methods for cell and structure arrays (see “Heterogeneous Data” on page 2-7).

Dataset Arrays

Dataset arrays are implemented as objects of the `dataset` class. Methods of the class are used to display, summarize, convert, concatenate, and access the collected data. Many of these methods are invoked using operations analogous to those for numerical arrays, and do not need to be called directly (for example, `[]` invokes `horzcat`). Other methods, such as `sortrows`, must be called directly.

Create Dataset Arrays

Dataset arrays are variables created with `dataset`. For example, the following creates a dataset array from observations that are a combination of categorical and numerical measurements:

```
load fisheriris
NumObs = size(meas,1);
NameObs = strcat({'Obs'},num2str((1:NumObs)','%-d'));
iris = dataset({nominal(species),'species'},...
              {meas,'SL','SW','PL','PW'},...
              'ObsNames',NameObs);
```

```
iris(1:5,:)
```

```
ans =
```

	species	SL	SW	PL	PW
Obs1	setosa	5.1	3.5	1.4	0.2
Obs2	setosa	4.9	3	1.4	0.2
Obs3	setosa	4.7	3.2	1.3	0.2
Obs4	setosa	4.6	3.1	1.5	0.2
Obs5	setosa	5	3.6	1.4	0.2

When creating a dataset array, variable names and observation names can be assigned together with the data. Other metadata associated with the array can be assigned with `set` and accessed with `get`:

```
iris = set(iris,'Description','Fisher''s Iris Data');
```

```
get(iris)
  Description: 'Fisher's Iris Data'
  Units: {}
  DimNames: {'Observations' 'Variables'}
  UserData: []
  ObsNames: {150x1 cell}
  VarNames: {'species' 'SL' 'SW' 'PL' 'PW'}
```

Create Categorical Arrays

In this section...
“Create Nominal Arrays” on page 2-24
“Create Ordinal Arrays” on page 2-26

Create Nominal Arrays

This example shows how to create nominal arrays using `nominal`.

Load sample data.

```
load('fisheriris')
```

The variable `species` is a 150-by-1 cell array of strings containing the species name for each observation. The unique species types are `setosa`, `versicolor`, and `virginica`.

```
unique(species)
```

```
ans =
```

```
    'setosa'  
    'versicolor'  
    'virginica'
```

Create a nominal array.

Convert `species` to a nominal array using the categories occurring in the data.

```
speciesNom = nominal(species);  
class(speciesNom)
```

```
ans =
```

```
nominal
```

The nominal array, `speciesNom`, has three levels corresponding to the three unique species. The levels of a categorical array are the set of possible values that its elements can take.


```
getlevels(speciesNom)

ans =

    setosa    versicolor    virginica
```

A categorical array can have more levels than actually appear in the data. For example, a categorical array named `AllSizes` might have levels `small`, `medium`, and `large`, but you might only have observations that are `medium` and `large` in your data. To see which levels of a categorical array are actually present in the data, use `unique`, for instance, `unique(AllSizes)`.

Each level has a label, which is a string used to name the level. By default, nominal labels the category levels with the values occurring in the data. For `speciesNom`, these labels are the species types.

```
getlabels(speciesNom)

ans =

    'setosa'    'versicolor'    'virginica'
```

Specify your own category labels.

You can specify your own labels for each category level. You can specify labels when you create the nominal array, or by using `setlabels`.

```
speciesNom2 = nominal(species,{'seto','vers','virg'});
getlabels(speciesNom2)

ans =

    'seto'    'vers'    'virg'
```

Verify that the new labels correspond to the original labels in `speciesNom`.

```
isequal(speciesNom=='setosa',speciesNom2=='seto')

ans =

    1
```

The logical value 1 indicates that the two labels, 'setosa' and 'seto', correspond to the same observations.

Create Ordinal Arrays

This example shows how to create ordinal arrays using `ordinal`.

Load sample data.

```
AllSizes = {'medium', 'large', 'small', 'small', 'medium', ...  
           'large', 'medium', 'small'};
```

The created variable, `AllSizes`, is a cell array of strings containing size measurements on eight objects.

Create an ordinal array.

Create an ordinal array with category levels and labels corresponding to the values in the cell array (the default levels and labels).

```
sizeOrd = ordinal(AllSizes);  
getlevels(sizeOrd)
```

```
ans =
```

```
    large    medium    small
```

```
getlabels(sizeOrd)
```

```
ans =
```

```
'large'    'medium'    'small'
```

By default, `ordinal` uses the original strings as category labels. The default order of the categories is ascending alphabetical order.

Suppose that you want to include additional levels for the ordinal array, `xsmall` and `xlarge`, even though they do not occur in the original data. To specify additional levels, use the third input argument to `ordinal`.

```
sizeOrd2 = ordinal(AllSizes, {}, ...  
                  {'xsmall', 'small', 'medium', 'large', 'xlarge'});
```

```
getlevels(sizeOrd2)

ans =

    xsmall    small    medium    large    xlarge
```

To see which levels are actually present in the data, use `unique`.

```
unique(sizeOrd2)

ans =

    small    medium    large
```

Specify the category order.

Convert `AllSizes` to an ordinal array with categories `small < medium < large`. Generally, an ordinal array is distinct from a nominal array because there is a natural ordering for levels of an ordinal array. You can use the third input argument to `ordinal` to specify the ascending order of the levels. Here, the order of the levels is smallest to largest.

```
sizeOrd = ordinal(AllSizes, {}, {'small', 'medium', 'large'});
getlevels(sizeOrd)

ans =

    small    medium    large
```

The second input argument for `ordinal` is a list of labels for the category levels. When you use braces `{}` for the level labels, `ordinal` uses the labels specified in the third input argument (the labels come from the levels present in the data if only one input argument is used).

Verify that the first object (with size `medium`) is smaller than the second object (with size `large`).

```
sizeOrd(1) < sizeOrd(2)

ans =

    1
```

The logical value 1 indicates that the inequality holds.

See Also

`nominal` | `ordinal` | `getlabels` | `getlevels` | `unique` | `isequal` |

Related Examples

- “Change Category Labels” on page 2-29
- “Reorder Category Levels” on page 2-31
- “Merge Category Levels” on page 2-39
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Change Category Labels

This example shows how to change the labels for category levels in categorical arrays using `setlabels`. You also have the option to specify labels when creating a categorical array.

Load sample data.

```
load('carsmall')
```

The variable `Cylinders` contains the number of cylinders in 100 sample cars.

```
unique(Cylinders)
```

```
ans =
```

```
    4  
    6  
    8
```

The sample has 4-, 6-, and 8-cylinder cars.

Create an ordinal array.

Convert `Cylinders` to a nominal array with the default category labels (taken from the values in the data).

```
cyl = ordinal(Cylinders);  
getlabels(cyl)
```

```
ans =
```

```
    '4'    '6'    '8'
```

`ordinal` created labels using the integer values in `Cylinders`, but you should provide labels for numeric data.

Change category labels.

Relabel the categories in `cyl` to `Four`, `Six`, and `Eight`.

```
cyl = setlabels(cyl ,{'Four', 'Six', 'Eight'});
```

```
getlabels(cyl)

ans =
      'Four'      'Six'      'Eight'
```

Alternatively, you can specify category labels when you create a categorical array using the second input argument.

```
cyl2 = ordinal(Cylinders,{'Four','Six','Eight'});
getlabels(cyl2)

ans =
      'Four'      'Six'      'Eight'
```

See Also

[ordinal](#) | [getlabels](#) | [setlabels](#) |

Related Examples

- “Reorder Category Levels” on page 2-31
- “Add and Drop Category Levels” on page 2-41
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Reorder Category Levels

In this section...

“Reorder Category Levels in Ordinal Arrays” on page 2-31

“Reorder Category Levels in Nominal Arrays” on page 2-32

Reorder Category Levels in Ordinal Arrays

This example shows how to reorder the category levels in an ordinal array using `reorderlevels`.

Load sample data.

```
AllSizes = {'medium', 'large', 'small', 'small', 'medium', ...
            'large', 'medium', 'small'};
```

The created variable, `AllSizes`, is a cell array of strings containing size measurements on eight objects.

Create an ordinal array.

Convert `AllSizes` to an ordinal array without specifying the order of the category levels.

```
size = ordinal(size);
getlevels(size)
```

```
ans =
```

```
      large      medium      small
```

By default, the categories are ordered by their labels in ascending alphabetical order, `large < medium < small`. For example, check whether or not the first object (which has size `medium`) is smaller than the second object (which has size `large`).

```
size(1) < size(2)
```

```
ans =
```

```
0
```

The logical value 0 indicates that the medium object is not smaller than the large object.

Reorder category levels.

Reorder the category levels so that `small < medium < large`.

```
size = reorderlevels(size, {'small', 'medium', 'large'});  
getlevels(size)
```

```
ans =
```

```
    small    medium    large
```

Verify that the first object is now smaller than the second object.

```
size(1) < size(2)
```

```
ans =
```

```
1
```

The logical value 1 indicates that the expected inequality now holds.

Reorder Category Levels in Nominal Arrays

This example shows how to reorder the category levels in nominal arrays using `reorderlevels`. By definition, nominal array categories have no natural ordering. However, you might want to change the order of levels for display or analysis purposes. For example, when fitting a regression model with categorical covariates, `LinearModel.fit` uses the first level of a nominal independent variable as the reference category.

Load sample data.

```
load('hospital')
```

The dataset array, `hospital`, contains variables measured on 100 sample patients. The variable `Weight` contains the weight of each patient. The

variable `Sex` is a nominal variable containing the gender, Male or Female, for each patient.

```
getlevels(hospital.Sex)
```

```
ans =
```

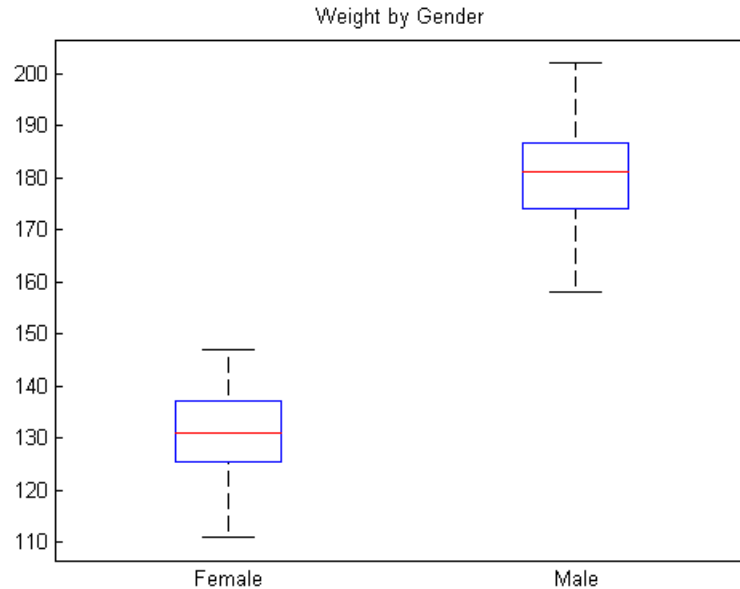
```
      Female      Male
```

By default, the order of the nominal categories is in ascending alphabetical order of the labels.

Plot data grouped by category level.

Draw box plots of weight, grouped by gender.

```
figure()  
boxplot(hospital.Weight,hospital.Sex)  
title('Weight by Gender')
```



The box plots appear in the same alphabetical order returned by `getlevels`.

Change the category order.

Change the order of the category levels.

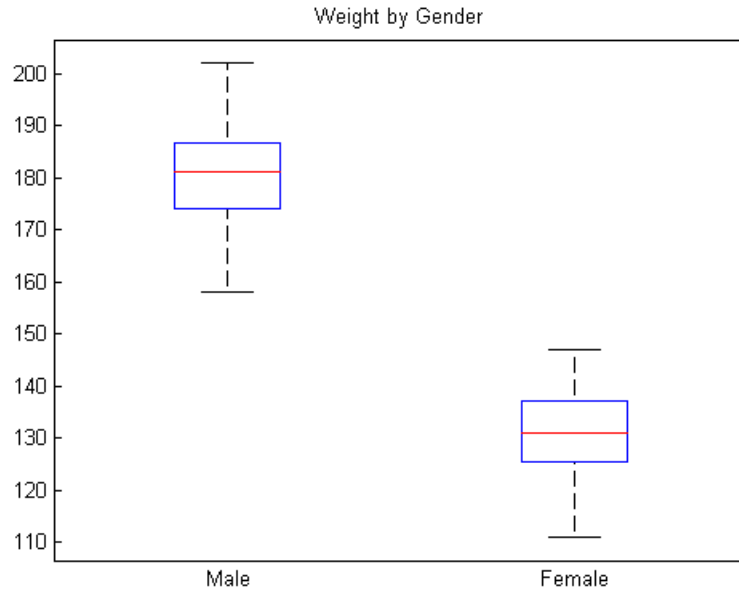
```
hospital.Sex = reorderlevels(hospital.Sex,{'Male', 'Female'});  
getlevels(hospital.Sex)
```

```
ans =
```

```
      Male      Female
```

The levels are in the newly specified order. Draw box plots of weight by gender.

```
figure()  
boxplot(hospital.Weight,hospital.Sex)  
title('Weight by Gender')
```



The order of the box plots corresponds to the new level order.

See Also

[nominal](#) | [ordinal](#) | [getlevels](#) | [LinearModel.fit](#) | [reorderlevels](#) |

Related Examples

- “Change Category Labels” on page 2-29
- “Merge Category Levels” on page 2-39
- “Add and Drop Category Levels” on page 2-41
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Categorize Numeric Data

This example shows how to categorize numeric data into a categorical ordinal array using `ordinal`. This is useful for discretizing continuous data.

Load sample data.

```
load('hospital')
```

The dataset array, `hospital`, contains variables measured on a sample of patients. Compute the minimum, median, and maximum of the variable `Age`.

```
quantile(hospital.Age,[0,.5,1])
```

```
ans =  
  
    25    39    50
```

The variable `Age` has the ages of each patient, ranging from 25 to 50.

Convert a numeric array to an ordinal array.

Group patients into the age categories Under 30, 30-39, Over 40.

```
hospital.AgeCat = ordinal(hospital.Age,{'Under 30','30-39','Over 40'},...  
                           [],[25,30,40,50]);  
getlevels(hospital.AgeCat)
```

```
ans =  
  
    Under 30    30-39    Over 40
```

The last input argument to `ordinal` has the endpoints for the categories. The first category begins at age 25, the second at age 30, and so on. The last category contains ages 40 and above, so begins at 40 and ends at 50 (the maximum age in the data set). To specify three categories, you must specify four endpoints (the last endpoint is the upper bound of the last category).

Display the age and age category for the second patient.

```
hospital.Age(2)
```

```
ans =
    43
hospital.AgeCat(2)
```

```
ans =
    Over 40
```

When you discretize a numeric array into categories, the categorical array loses all information about the actual numeric values. In this example, `AgeCat` is not numeric, and you cannot recover the raw data values from it.

Categorize a numeric array into quartiles.

The variable `Weight` has weight measurements for the sample patients. Categorize the patient weights into four categories, by quartile.

```
p = 0:.25:1;
breaks = quantile(hospital.Weight,p);
hospital.WeightQ = ordinal(hospital.Weight,{'Q1','Q2','Q3','Q4'},...
                           [],breaks);
getlevels(hospital.WeightQ)
```

```
ans =
    Q1      Q2      Q3      Q4
```

Display the weight and weight quartile for the second patient.

```
hospital.Weight(2)
ans =
    163
hospital.WeightQ(2)
ans =
    Q3
```

Summary statistics grouped by category levels.

Compute the mean systolic and diastolic blood pressure for each age and weight category.

```
grpstats(hospital, {'AgeCat', 'WeightQ'}, 'mean', 'DataVars', 'BloodPressure')
```

ans =

	AgeCat	WeightQ	GroupCount	mean_BloodPressure	
Under 30_Q1	Under 30	Q1	6	123.17	79.667
Under 30_Q2	Under 30	Q2	3	120.33	79.667
Under 30_Q3	Under 30	Q3	2	127.5	86.5
Under 30_Q4	Under 30	Q4	4	122	78
30-39_Q1	30-39	Q1	12	121.75	81.75
30-39_Q2	30-39	Q2	9	119.56	82.556
30-39_Q3	30-39	Q3	9	121	83.222
30-39_Q4	30-39	Q4	11	125.55	87.273
Over 40_Q1	Over 40	Q1	7	122.14	84.714
Over 40_Q2	Over 40	Q2	13	123.38	79.385
Over 40_Q3	Over 40	Q3	14	123.07	84.643
Over 40_Q4	Over 40	Q4	10	124.6	85.1

The variable `BloodPressure` is a matrix with two columns. The first column is systolic blood pressure, and the second column is diastolic blood pressure. The group in the sample with the highest mean diastolic blood pressure, 87.273, is aged 30–39 and in the highest weight quartile, 30-39_Q4.

See Also

`ordinal` | `grpstats`

Related Examples

- “Create Categorical Arrays” on page 2-24
- “Merge Category Levels” on page 2-39
- “Plot Data Grouped by Category” on page 2-45
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Merge Category Levels

This example shows how to merge categories in a categorical array using `mergelevels`. This is useful for collapsing categories with few observations.

Load sample data.

```
load('carsmall')
```

Create a nominal array.

The variable `Origin` is a character array containing the country of origin for 100 sample cars. Convert `Origin` to a nominal array.

```
Origin = nominal(Origin);
getlevels(Origin)
```

```
ans =
```

```
      France      Germany      Italy      Japan      Sweden      USA
```

There are six unique countries of origin in the data.

```
tabulate(Origin)
```

Value	Count	Percent
France	4	4.00%
Germany	9	9.00%
Italy	1	1.00%
Japan	15	15.00%
Sweden	2	2.00%
USA	69	69.00%

There are relatively few observations in each European country.

Merge categories.

Merge the categories `France`, `Germany`, `Italy`, and `Sweden` into one category called `Europe`.

```
Origin = mergelevels(Origin,{'France','Germany','Italy','Sweden'},...
                    'Europe');
```

```
getlevels(Origin)
```

```
ans =
```

```
      Japan      USA      Europe
```

The variable `Origin` now has only three category levels.

```
tabulate(Origin)
```

Value	Count	Percent
Japan	15	15.00%
USA	69	69.00%
Europe	16	16.00%

The category `Europe` has the 16% of observations that were previously distributed across four countries.

See Also

`nominal` | `mergelevels` |

Related Examples

- “Create Categorical Arrays” on page 2-24
- “Add and Drop Category Levels” on page 2-41
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Add and Drop Category Levels

This example shows how to add and drop levels from a categorical array.

Load sample data.

```
load('examgrades')
```

The array `grades` contains exam scores from 0 to 100 on five exams for a sample of 120 students.

Create an ordinal array.

Assign letter grades to each student for each test using these categories.

Grade Range	Letter Grade
100	A+
90–99	A
80–89	B
70–79	C
60–69	D

```
letter = ordinal(grades,{'D','C','B','A','A+'},[],...
                 [60,70,80,90,100,100]);
getlevels(letter)
```

```
ans =
```

```
      D      C      B      A      A+
```

There are five grade categories, in the specified order $D < C < B < A < A+$.

Check for undefined categories.

Check whether or not there are any exam scores that do not fall into the five letter categories.

```
any(isundefined(letter))
```

```
ans =  
      1      0      1      1      0
```

Recall that there are five exam scores for each student. The previous command returns a logical value for each of the five exams, indicating whether there are any scores that are `<undefined>`. There are scores for the first, third, and fourth exams that are `<undefined>`, that is, missing a category level. You can find the exam scores that do not have a letter grade using the `isundefined` logical condition.

```
grades(isundefined(letter))
```

```
ans =  
      55  
      59  
      58  
      59  
      54  
      57  
      56  
      59  
      59  
      50  
      59  
      52
```

The exam scores that are in the 50s do not have a letter grade.

Add a new category.

Put all scores that are `<undefined>` into a new category labeled D-.

```
letter(isundefined(letter)) = 'D-';
```

```
Warning: Categorical level 'D-' being added.  
> In categorical.subsasgn at 55
```

```
getlevels(letter)
```

```
ans =
      D      C      B      A      A+      D-
```

The ordinal variable, `letter`, has a new category added to the end. Reorder the categories so that `D- < D`.

```
letter = reorderlevels(letter,{'D-', 'D', 'C', 'B', 'A', 'A+'});
getlevels(letter)
```

```
ans =
      D-      D      C      B      A      A+
```

Now that all exam scores have a letter grade, count how many students received a higher letter grade on the second test than on the first test.

```
sum(letter(:,2) > letter(:,1))
```

```
ans =
      32
```

Thirty-two students improved their letter grade between the first two exams.

Drop a category.

Count the number of A+ scores in each of the five exams.

```
sum(letter=='A+')
ans =
      0      0      0      0      0
```

There are no A+ scores on any of the five exams. Drop the category A+ from the ordinal variable, `letter`.

```
letter = droplevels(letter, 'A+');
getlevels(letter)
```

```
ans =
```

D- D C B A

Category A+ is no longer in the ordinal variable, letter.

See Also

`ordinal` | `isundefined` | `reorderlevels` | `droplevels` |

Related Examples

- “Create Categorical Arrays” on page 2-24
- “Reorder Category Levels” on page 2-31
- “Merge Category Levels” on page 2-39
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Plot Data Grouped by Category

This example shows how to plot data grouped by the levels of a categorical variable.

Load sample data.

```
load('carsmall')
```

The variable `Acceleration` contains acceleration measurements on 100 sample cars. The variable `Origin` is a character array containing the country of origin for each car.

Create a nominal array.

Convert `Origin` to a nominal array.

```
Origin = nominal(Origin);  
getlevels(Origin)
```

```
ans =
```

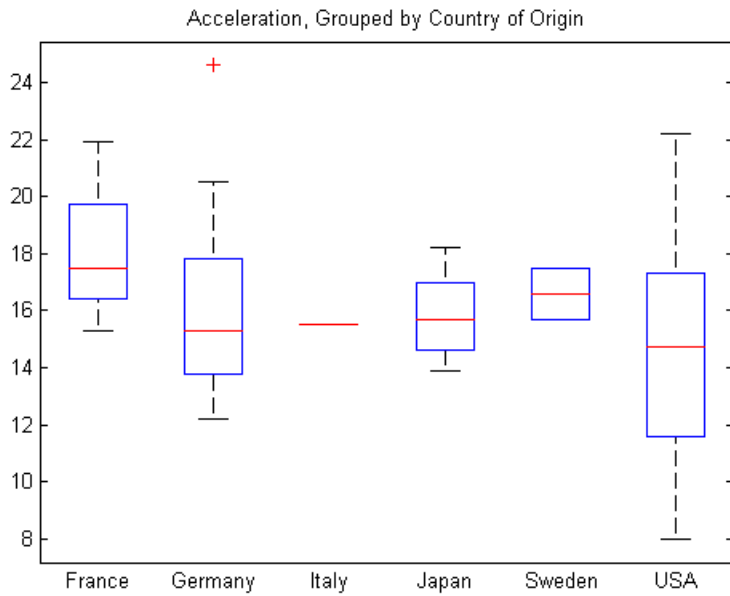
```
      France      Germany      Italy      Japan      Sweden      USA
```

There are six unique countries of origin in the sample. By default, `nominal` orders the countries in ascending alphabetical order.

Plot data grouped by category.

Draw box plots for `Acceleration`, grouped by `Origin`.

```
figure()  
boxplot(Acceleration,Origin)  
title('Acceleration, Grouped by Country of Origin')
```



The box plots appear in the same order as the categorical levels (use `reorderlevels` to change the order of the categories).

Few observations have Italy as the country of origin. Tabulate the number of sample cars from each country.

```
tabulate(Origin)
```

Value	Count	Percent
France	4	4.00%
Germany	9	9.00%
Italy	1	1.00%
Japan	15	15.00%
Sweden	2	2.00%
USA	69	69.00%

Only one car is made in Italy.

Drop a category.

Delete the Italian car from the sample.

```
Acceleration2 = Acceleration(Origin!='Italy');
Origin2 = Origin(Origin!='Italy');
tabulate(Origin2)
```

This output shows that even though the car from Italy is no longer in the sample, the nominal variable, `Origin2`, still has the category `Italy`.

```
getlevels(Origin2)
```

```
ans =
```

```
      France      Germany      Italy      Japan      Sweden      USA
```

Note that this is intentional—the levels of a categorical array do not necessarily coincide with the values. Use `droplevels` to remove the `Italy` category.

```
tabulate(Origin2)
  Value      Count      Percent
  France         4      4.04%
  Germany        9      9.09%
  Italy          0      0.00%
  Japan         15     15.15%
  Sweden         2      2.02%
  USA           69     69.70%
```

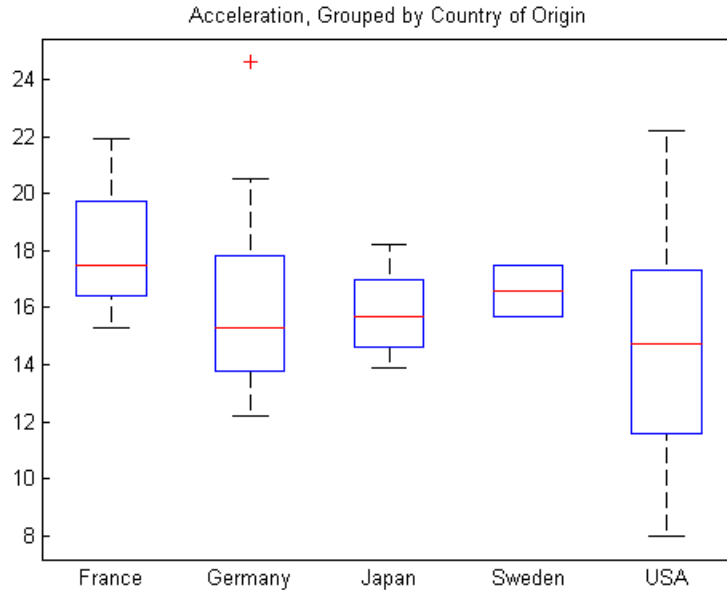
```
Origin2 = droplevels(Origin2,'Italy');
tabulate(Origin2)
```

```
tabulate(Origin2)
  Value      Count      Percent
  France         4      4.04%
  Germany        9      9.09%
  Japan         15     15.15%
  Sweden         2      2.02%
  USA           69     69.70%
```

The `Italy` category is no longer in the nominal array, `Origin2`.

Draw box plots of `Acceleration2`, grouped by `Origin2`.

```
figure()  
boxplot(Acceleration2,Origin2)  
title('Acceleration, Grouped by Country of Origin')
```



The plot no longer includes the car from Italy.

See Also

[droplevels](#) | [nominal](#) | [reorderlevels](#) | [boxplot](#)

Related Examples

- “Test Differences Between Category Means” on page 2-49
- “Summary Statistics Grouped by Category” on page 2-58
- “Regression with Categorical Covariates” on page 2-80

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64
- “Grouping Variables” on page 2-72

Test Differences Between Category Means

This example shows how to test for significant differences between category (group) means using a *t*-test, two-way ANOVA (analysis of variance), and ANOCOVA (analysis of covariance) analysis.

The goal is determining if the expected miles per gallon for a car depends on the decade in which it was manufactured, or the location where it was manufactured.

Load sample data.

```
load('carsmall')
```

The variable MPG has miles per gallon measurements on a sample of 100 cars. The variables Model_Year and Origin contain the model year and country of origin for each car.

Create a factor for the decade of manufacture.

The first factor of interest is the decade of manufacture. There are three manufacturing years in the data.

```
unique(Model_Year)
```

```
ans =
```

```
70
76
82
```

Create an ordinal array named Decade. Merge the observations from years 70 and 76 into a category labeled 1970s, and put the observations from 82 into a category labeled 1980s.

```
Decade = ordinal(Model_Year,{'1970s','1980s'},[],[70 77 82]);
getlevels(Decade)
```

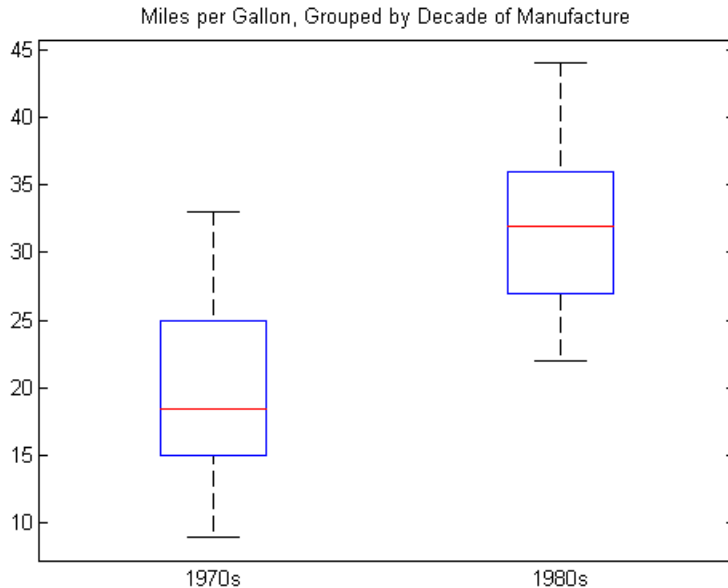
```
ans =
```

```
1970s    1980s
```

Conduct a two-sample t-test for equal group means.

Draw a box plot of miles per gallon, grouped by the decade of manufacture.

```
figure()  
boxplot(MPG,Decade)  
title('Miles per Gallon, Grouped by Decade of Manufacture')
```



The box plot suggests that miles per gallon is higher in cars manufactured during the 1980s compared to the 1970s. Compute the mean and variance of miles per gallon for each decade.

```
[xbar,s2,grp] = grpstats(MPG,Decade,{'mean','var','gname'})
```

```
xbar =
```

```
19.7857  
31.7097
```

```

s2 =

    35.1429
    29.0796

grp =

    '1970s'
    '1980s'

```

This output shows that the mean miles per gallon in the 1980s was 31.71, compared to 19.79 in the 1970s. The variances in the two groups are similar.

Conduct a two-sample t -test, assuming equal variances, to test for a significant difference between the group means. The hypothesis is

$$H_0 : \mu_{70} = \mu_{80}$$

$$H_A : \mu_{70} \neq \mu_{80}$$

```

MPG70 = MPG(Decade=='1970s');
MPG80 = MPG(Decade=='1980s');
[h,p] = ttest2(MPG70,MPG80)

```

```

h =

     1

p =

    3.4809e-15

```

The logical value 1 indicates the null hypothesis is rejected at the default 0.05 significance level. The p-value for the test is very small. There is sufficient evidence that the mean miles per gallon in the 1980s differs from the mean miles per gallon in the 1970s.

Create a factor for the location of manufacture.

The second factor of interest is the location of manufacture. First, convert `Origin` to a nominal array.

```
Location = nominal(Origin);  
tabulate(Location)
```

```
tabulate(Location)  
  Value    Count    Percent  
  France     4     4.00%  
  Germany    9     9.00%  
  Italy       1     1.00%  
  Japan     15    15.00%  
  Sweden     2     2.00%  
  USA       69    69.00%
```

There are six different countries of manufacture. The European countries have relatively few observations. Combine the categories France, Germany, Italy, and Sweden into a new category named Europe.

```
Location = mergelevels(Location,{'France','Germany','Italy','Sweden'},...  
                          'Europe');  
tabulate(Location)
```

```
  Value    Count    Percent  
  Japan     15    15.00%  
  USA       69    69.00%  
  Europe    16    16.00%
```

Compute the mean miles per gallon, grouped by the location of manufacture.

```
[xbar,grp] = grpstats(MPG,Location,{'mean','gname'})
```

```
xbar =
```

```
 31.8000  
 21.1328  
 26.6667
```

```
grp =
```

'Japan'
 'USA'
 'Europe'

This result shows that average miles per gallon is lowest for the sample of cars manufactured in the U.S.

Conduct two-way ANOVA.

Conduct a two-way ANOVA to test for differences in expected miles per gallon between factor levels for Decade and Location.

The statistical model is

$$MPG_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}, \quad i = 1, 2; j = 1, 2, 3,$$

where MPG_{ij} is the response, miles per gallon, for cars made in decade i at location j . The treatment effects for the first factor, decade of manufacture, are the α_i terms (constrained to sum to zero). The treatment effects for the second factor, location of manufacture, are the β_j terms (constrained to sum to zero). The ε_{ij} are uncorrelated, normally distributed noise terms.

The hypotheses to test are equality of decade effects,

$$H_0 : \alpha_1 = \alpha_2 = 0$$

$$H_A : \text{at least one } \alpha_i \neq 0,$$

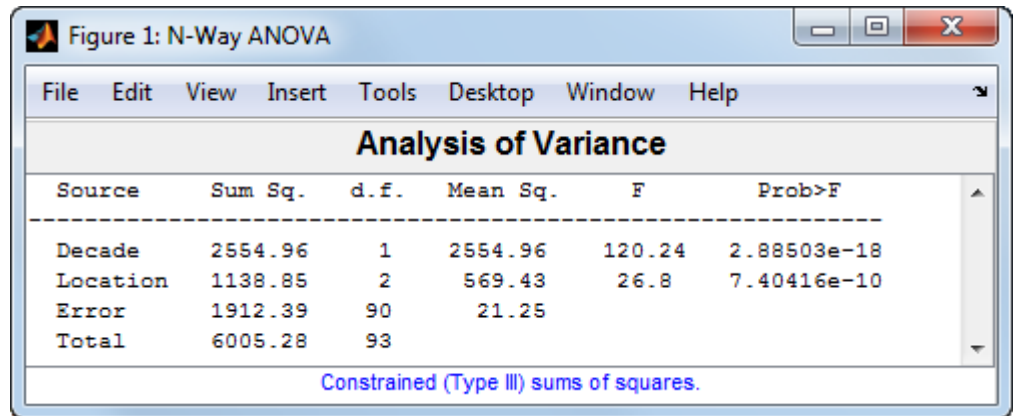
and equality of location effects,

$$H_0 : \beta_1 = \beta_2 = \beta_3 = 0$$

$$H_A : \text{at least one } \beta_j \neq 0.$$

You can conduct a multiple-factor ANOVA using `anovan`.

```
anovan(MPG, {Decade, Location}, 'varnames', {'Decade', 'Location'});
```



This output shows the results of the two-way ANOVA. The p-value for testing the equality of decade effects is $2.88503e-18$, so the null hypothesis is rejected at the 0.05 significance level. The p-value for testing the equality of location effects is $7.40416e-10$, so this null hypothesis is also rejected.

Conduct ANOCOVA analysis.

A potential confounder in this analysis is car weight. Cars with greater weight are expected to have lower gas mileage. Include the variable `Weight` as a continuous covariate in the ANOVA; that is, conduct an ANOCOVA analysis.

Assuming parallel lines, the statistical model is

$$MPG_{ijk} = \mu + \alpha_i + \beta_j + \gamma Weight_{ijk} + \varepsilon_{ijk}, \quad i = 1, 2; \quad j = 1, 2, 3; \quad k = 1, \dots, 100.$$

The difference between this model and the two-way ANOVA model is the inclusion of the continuous predictor, $Weight_{ijk}$, the weight for the k th car, which was made in the i th decade and in the j th location. The slope parameter is γ .

Add the continuous covariate as a third group in the second `anovan` input argument. Use the name-value pair argument `Continuous` to specify that `Weight` (the third group) is continuous.

```
anovan(MPG, {Decade, Location, Weight}, 'Continuous', 3, ...
        'varnames', {'Decade', 'Location', 'Weight'});
```

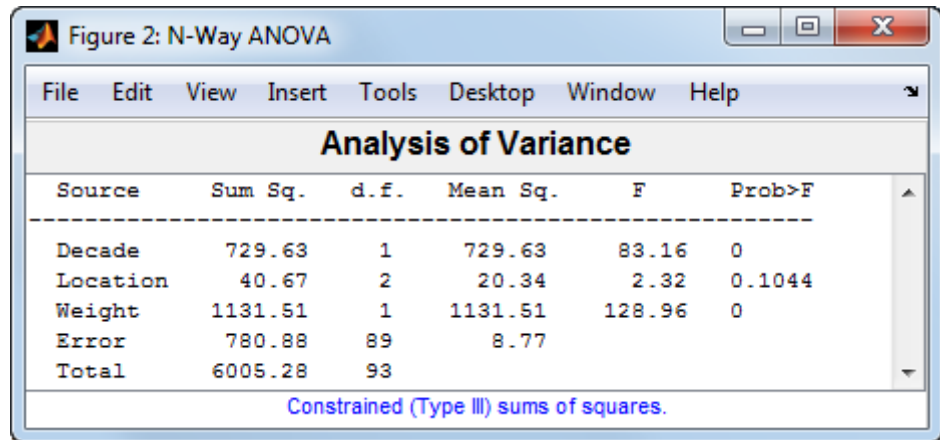


Figure 2: N-Way ANOVA

File Edit View Insert Tools Desktop Window Help

Analysis of Variance

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Decade	729.63	1	729.63	83.16	0
Location	40.67	2	20.34	2.32	0.1044
Weight	1131.51	1	1131.51	128.96	0
Error	780.88	89	8.77		
Total	6005.28	93			

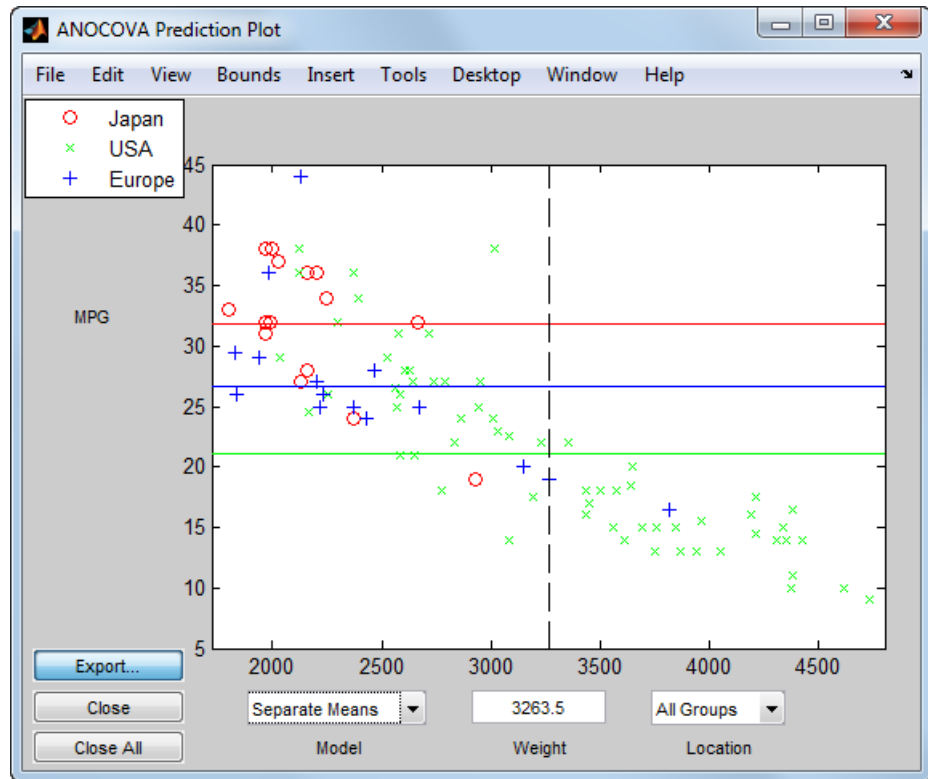
Constrained (Type III) sums of squares.

This output shows that when car weight is considered, there is insufficient evidence of a manufacturing location effect (p-value = 0.1044).

You can use the interactive `aoctool` to explore this result.

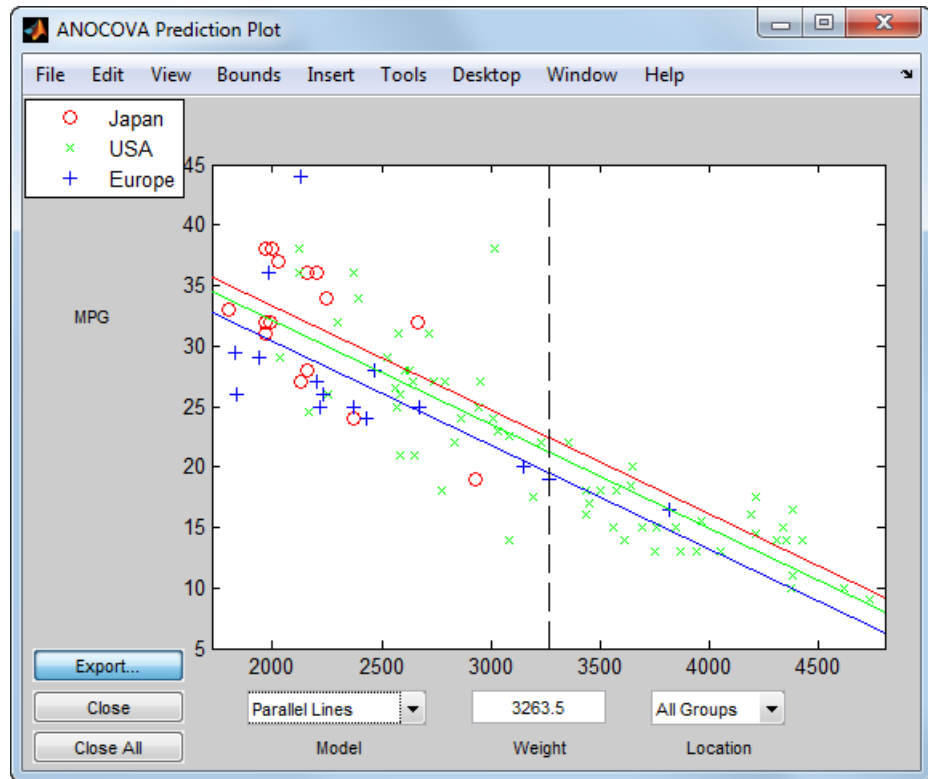
```
aoctool(Weight,MPG,Location);
```

This command opens three dialog boxes. In the ANOCOVA Prediction Plot dialog box, select the **Separate Means** model.



This output shows that when you do not include **Weight** in the model, there are fairly large differences in the expected miles per gallon among the three manufacturing locations. Note that here the model does not adjust for the decade of manufacturing.

Now, select the **Parallel Lines** model.



When you include **Weight** in the model, the difference in expected miles per gallon among the three manufacturing locations is much smaller.

See Also

[ordinal](#) | [nominal](#) | [boxplot](#) | [grpstats](#) | [ttest2](#) | [anovan](#) | [aoctool](#)

Related Examples

- “Plot Data Grouped by Category” on page 2-45
- “Summary Statistics Grouped by Category” on page 2-58
- “Regression with Categorical Covariates” on page 2-80

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64
- “Grouping Variables” on page 2-72

Summary Statistics Grouped by Category

This example shows how to compute summary statistics grouped by levels of a categorical variable. You can compute group summary statistics for a numeric array or a dataset array using `grpstats`.

Load sample data.

```
load('hospital')
```

The dataset array, `hospital`, has 7 variables (columns) and 100 observations (rows).

Compute summary statistics by category.

The variable `Sex` is a nominal array with two levels, `Male` and `Female`. Compute the minimum and maximum weights for each gender.

```
stats = grpstats(hospital, 'Sex', {'min', 'max'}, 'DataVars', 'Weight')
```

```
stats =
```

	Sex	GroupCount	min_Weight	max_Weight
Female	Female	53	111	147
Male	Male	47	158	202

The dataset array, `stats`, has observations corresponding to the levels of the variable `Sex`. The variable `min_Weight` contains the minimum weight for each group, and the variable `max_Weight` contains the maximum weight for each group.

Compute summary statistics by multiple categories.

The variable `Smoker` is a logical array with value 1 for smokers and value 0 for nonsmokers. Compute the minimum and maximum weights for each gender and smoking combination.

```
stats = grpstats(hospital, {'Sex', 'Smoker'}, {'min', 'max'}, ...
                'DataVars', 'Weight')
```

```
stats =
```

	Sex	Smoker	GroupCount	min_Weight	max_Weight
Female_0	Female	false	40	111	147
Female_1	Female	true	13	115	146
Male_0	Male	false	26	158	194
Male_1	Male	true	21	164	202

The dataset array, `stats`, has an observation row for each combination of levels of `Sex` and `Smoker` in the original data.

See Also

`dataset` | `nominal` | `grpstats`

Related Examples

- “Plot Data Grouped by Category” on page 2-45
- “Test Differences Between Category Means” on page 2-49
- “Calculations on Dataset Arrays” on page 2-132

Concepts

- “Grouping Variables” on page 2-72
- “Categorical Arrays” on page 2-62
- “Dataset Arrays” on page 2-156

Sort Ordinal Arrays

This example shows how to determine sorting order for ordinal arrays.

Load sample data.

```
AllSizes = {'medium','large','small','small','medium',...  
           'large','medium','small'};
```

The created variable, `AllSizes`, is a cell array of strings containing size measurements on eight objects.

Create an ordinal array.

Convert `AllSizes` to an ordinal array with levels `small < medium < large`.

```
AllSizes = ordinal(AllSizes, {}, {'small','medium','large'});  
getlevels(AllSizes)
```

```
ans =  
  
    small    medium    large
```

Sort the ordinal array.

When you sort ordinal arrays, the sorted observations are in the same order as the category levels.

```
sizeSort = sort(AllSizes);  
sizeSort(:)
```

```
ans =  
  
    small  
    small  
    small  
    medium  
    medium  
    medium  
    large  
    large
```

The sorted ordinal array, `sizeSort`, contains the observations ordered from small to large.

See Also

`ordinal` | `sort` |

Related Examples

- “Reorder Category Levels” on page 2-31
- “Add and Drop Category Levels” on page 2-41

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Categorical Arrays

In this section...
“What Are Categorical Arrays?” on page 2-62
“Categorical Array Conversion” on page 2-62

What Are Categorical Arrays?

Categorical arrays are Statistics Toolbox data types for storing categorical values. Categorical arrays store data that have a finite set of discrete levels, which might or might not have a natural order. There are two types of categorical arrays:

- **ordinal** arrays store categorical values with ordered levels. For example, an ordinal variable might have levels {small, medium, large}.
- **nominal** arrays store categorical values with unordered levels. For example, a nominal variable might have levels {red, blue, green}.

In experimental design, these variables are often called *factors*, with ordered or unordered *factor levels*.

Categorical arrays are convenient and memory efficient containers for storing categorical variables. In addition to storing information about which category each observation belongs to, categorical arrays store descriptive metadata including category labels and order.

Categorical arrays have associated methods that streamline common tasks such as merging categories, adding or dropping levels, and changing level labels.

Categorical Array Conversion

You can easily convert to and from categorical arrays. To create a nominal or ordinal array, use `nominal` or `ordinal`, respectively. You can convert these data types to categorical arrays:

- Numeric array

- Logical array
- Character array
- Cell array of strings

See Also

[ordinal](#) | [nominal](#) |

Related Examples

- “Create Categorical Arrays” on page 2-24
- “Summary Statistics Grouped by Category” on page 2-58
- “Plot Data Grouped by Category” on page 2-45
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Advantages of Using Categorical Arrays” on page 2-64
- “Grouping Variables” on page 2-72

Advantages of Using Categorical Arrays

In this section...
“Manipulate Category Levels” on page 2-64
“Analysis Using Categorical Arrays” on page 2-64
“Reduce Memory Requirements” on page 2-65

Manipulate Category Levels

When working with categorical variables and their levels, you’ll encounter some typical challenges. This table summarizes the functions you can use with categorical arrays to manipulate category levels. For additional functions, type `methods nominal` or `methods ordinal` at the command line, or see the `nominal` and `ordinal` reference pages.

Task	Function
Add new category levels	<code>addlevels</code>
Drop category levels	<code>droplevels</code>
Combine category levels	<code>mergelevels</code>
Reorder category levels	<code>reorderlevels</code>
Count the number of observations in each category	<code>levelcounts</code>
Change the label or name of category levels	<code>setlabels</code>
Create an interaction factor	<code>times</code>
Find observations that are not in a defined category	<code>isundefined</code>

Analysis Using Categorical Arrays

You can use categorical arrays in a variety of statistical analyses. For example, you might want to compute descriptive statistics for data grouped by the category levels, conduct statistical tests on differences between category means, or perform regression analysis using categorical predictors.

Statistics Toolbox functions that accept a grouping variable as an input argument accept categorical arrays. This includes descriptive functions such as:

- `grpstats`
- `gscatter`
- `boxplot`
- `gplotmatrix`

You can also use categorical arrays as input arguments to analysis functions and methods based on models, such as:

- `anovan`
- `LinearModel.fit`
- `GeneralizedLinearModel.fit`
- `NonLinearModel.fit`

When you use a categorical array as a predictor in these functions, the fitting function automatically recognizes the categorical predictor, and constructs appropriate dummy indicator variables for analysis. Alternatively, you can construct your own dummy indicator variables using `dummyvar`.

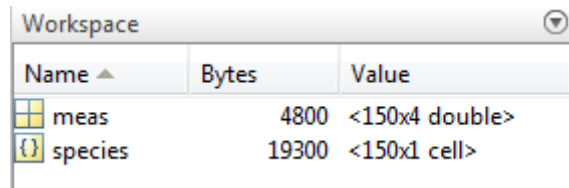
Reduce Memory Requirements

The levels of categorical variables are often defined as text strings, which can be costly to store and manipulate in a cell array of strings or `char` array. Categorical arrays separately store category membership and category labels, greatly reducing the amount of memory required to store the variable.

For example, load some sample data:

```
load('fisheriris')
```

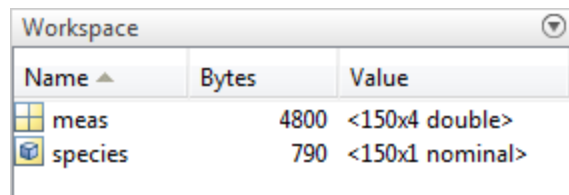
The variable `species` is a cell array of strings requiring 19,300 bytes of memory.



Name ▲	Bytes	Value
meas	4800	<150x4 double>
species	19300	<150x1 cell>

Convert species to a nominal array:

```
species = nominal(species);
```



Name ▲	Bytes	Value
meas	4800	<150x4 double>
species	790	<150x1 nominal>

There is a 95% reduction in memory required to store the variable.

See Also

[ordinal](#) | [nominal](#) |

Related Examples

- “Create Categorical Arrays” on page 2-24
- “Test Differences Between Category Means” on page 2-49
- “Regression with Categorical Covariates” on page 2-80
- “Index and Search Using Categorical Arrays” on page 2-67

Concepts

- “Categorical Arrays” on page 2-62
- “Grouping Variables” on page 2-72
- “Dummy Indicator Variables” on page 2-76

Index and Search Using Categorical Arrays

It is often useful to index and search data by its category, or group. If you store categories as string labels inside a cell array of strings or char array, it can be difficult to index and search the categories. When using categorical arrays, you can easily:

- **Index elements from particular categories.** For both nominal and ordinal arrays, you can use the logical operators `==` and `~=` to index the observations that are in, or not in, a particular category. For ordinal arrays, which have an encoded order, you can also use inequalities, `>`, `>=`, `<`, and `<=`, to find observations in categories above or below a particular category.
- **Search for members of a category.** In addition to the logical operator `==`, you can use `ismember` to find observations in a particular group.
- **Find elements that are not in a defined category.** Categorical arrays indicate which elements do not belong to a defined category by `<undefined>`. You can use `isundefined` to find observations missing a category.
- **Delete observations that are in a particular category.** You can use logical operators to include or exclude observations from particular categories. Even if you remove all observations from a category, the category level remains defined unless you remove it using `droplevels`.

The following brief examples illustrate several indexing and searching methods.

Load sample data.

```
load('carsmall')
```

Convert the char array, `Origin`, to a nominal array. This variable contains the country of origin, or manufacture, for each sample car.

```
Origin = nominal(Origin);
```

Search for observations in a category.

Determine if there any cars in the sample that were manufactured in Canada.

```
any(Origin=='Canada')
```

```
ans =
```

```
0
```

There are no sample cars manufactured in Canada. List the countries that are levels of Origin.

```
getlevels(Origin)
```

```
ans =
```

```
France      Germany      Italy      Japan      Sweden      USA
```

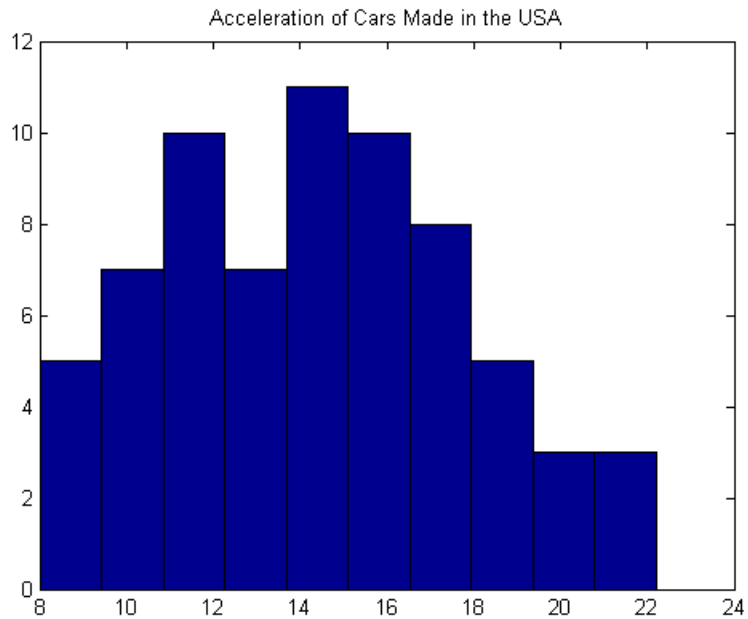
Index elements that are in a particular category.

Plot a histogram of the acceleration measurements for cars made in the U.S.

```
figure()
```

```
hist(Acceleration(Origin=='USA'))
```

```
title('Acceleration of Cars Made in the USA')
```



Delete observations that are in a particular category.

Delete all cars made in Sweden from `Origin`.

```
Origin = Origin(Origin~='Sweden');
any(ismember(Origin,'Sweden'))
```

```
ans =
```

```
0
```

The cars made in Sweden are deleted from `Origin`, but Sweden is still a level of `Origin`.

```
getlevels(Origin)
```

```
ans =
```

```
France    Germany    Italy    Japan    Sweden    USA
```

Remove Sweden from the levels of `Origin`.

```
Origin = droplevels(Origin, 'Sweden');  
getlevels(Origin)
```

```
ans =
```

```
      France      Germany      Italy      Japan      USA
```

Check for observations not in a defined category.

Get the indices for the cars made in France.

```
ix = find(Origin=='France')
```

```
ix =
```

```
    11  
    27  
    39  
    61
```

There are four cars from France. Remove France from the levels of `Origin`.

```
Origin = droplevels(Origin, 'France');
```

```
Warning: OLDLEVELS contains categorical levels that were present in the  
input array A. As a result, the output array B contains array elements  
that have undefined levels.
```

```
> In categorical.droplevels at 52
```

The warning indicates that you are dropping a category level that has elements in it. These observations are no longer in a defined category, indicated by `<undefined>`.

```
Origin(ix)
```

```
ans =
```

```
 <undefined>  
 <undefined>  
 <undefined>
```

```
<undefined>
```

You can use `isundefined` to search for observations with an undefined category.

```
find(isundefined(Origin))
```

```
ans =
```

```
11  
27  
39  
61
```

These indices correspond to the observations that were in category France, before that category was dropped from `Origin`.

See Also

`nominal` | `ordinal` | `ismember` | `isundefined` | `droplevels` |

Related Examples

- “Create Categorical Arrays” on page 2-24
- “Reorder Category Levels” on page 2-31
- “Merge Category Levels” on page 2-39
- “Add and Drop Category Levels” on page 2-41

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Grouping Variables

In this section...

“What Are Grouping Variables?” on page 2-72

“Group Definition” on page 2-73

“Analysis Using Grouping Variables” on page 2-73

“Missing Group Values” on page 2-74

What Are Grouping Variables?

Grouping variables are utility variables used to group, or categorize, observations. Grouping variables are useful for summarizing or visualizing data by group. A grouping variable can be any of these data types:

- Numeric vector
- Logical vector
- String array (also called character arrays)
- Cell array of strings
- Categorical vector

A grouping variable must have the same number of observations (rows) as the dataset array or numeric array you are grouping. Observations that have the same grouping variable value belong to the same group.

For example, the following variables comprise the same groups. Each grouping variable divides five observations into two groups. The first group contains the first and fourth observations. The other three observations are in the second group.

Data Type	Grouping Variable
Numeric vector	[1 2 2 1 2]
Logical vector	[0 1 1 0 1]

Data Type	Grouping Variable
Cell array of strings	{'Male', 'Female', 'Female', 'Male', 'Female'}
Categorical vector	Male Female Female Male Female

Grouping variables with string labels give each group a meaningful name. A categorical array is an efficient and flexible choice of grouping variable.

Group Definition

Typically, there are as many groups as unique values in the grouping variable. However, categorical arrays can have levels that are not represented in the data. The groups and the order of the groups depend on the data type of the grouping variable. Suppose **G** is a grouping variable.

- If **G** is a numeric or logical vector, then the groups correspond to the distinct values in **G**, in the sorted order of the unique values.
- If **G** is a string array or cell array of strings, then the groups correspond to the distinct strings in **G**, in the order of their first appearance.
- If **G** is a categorical vector, then the groups correspond to the unique category levels in **G**, in the order returned by `getlevels`.

Some functions, such as `grpstats`, accept multiple grouping variables specified as a cell array of grouping variables, for example, {**G1**, **G2**, **G3**}. In this case, the groups are defined by the unique combinations of values in the grouping variables. The order is decided first by the order of the first grouping variable, then by the order of the second grouping variable, and so on.

Analysis Using Grouping Variables

This table lists common tasks you might want to perform using grouping variables.

Grouping Task	Function Accepting Grouping Variable
Draw side-by-side boxplots for data in different groups.	boxplot
Draw a scatter plot with markers colored by group.	gscatter
Draw a scatter plot matrix with markers colored by group.	gplotmatrix
Compute summary statistics by group.	grpstats
Test for differences between group means.	anovan
Create an index vector from a grouping variable.	grp2idx

Missing Group Values

Grouping variables can have missing values provided you include a valid indicator.

Grouping Variable Data Type	Missing Value Indicator
Numeric vector	NaN
Logical vector	(Cannot be missing)
String array	Row of spaces
Cell array of strings	' '
Categorical vector	<undefined>

See Also

categorical | ordinal | nominal |

Related Examples

- “Plot Data Grouped by Category” on page 2-45
- “Summary Statistics Grouped by Category” on page 2-58

Concepts

- “Categorical Arrays” on page 2-62
- “Advantages of Using Categorical Arrays” on page 2-64

Dummy Indicator Variables

In this section...

“What Are Dummy Variables?” on page 2-76

“Creating Dummy Variables” on page 2-77

What Are Dummy Variables?

When performing regression analysis, it is common to include both continuous and categorical (quantitative and qualitative) predictor variables. When including a categorical independent variable, it is important not to input the variable as a numeric array. Numeric arrays have both order and magnitude. A categorical variable might have order (for example, an ordinal variable), but it does not have magnitude. Using a numeric array implies a known “distance” between the categories.

The appropriate way to include categorical predictors is as dummy indicator variables. An indicator variable has values 0 and 1. A categorical variable with c categories can be represented by $c - 1$ indicator variables.

For example, suppose you have a categorical variable with levels {Small,Medium,Large}. You can represent this variable using two dummy variables, as shown in this figure.

	X ₁	X ₂	
Small	0	0	Reference Group
Medium	1	0	
Large	0	1	

In this example, X_1 is a dummy variable that has value 1 for the `Medium` group, and 0 otherwise. X_2 is a dummy variable that has value 1 for the `Large` group, and 0 otherwise. Together, these two variables represent the three categories. Observations in the `Small` group have 0s for both dummy variables.

The category represented by all 0s is the *reference group*. When you include the dummy variables in a regression model, the coefficients of the dummy variables are interpreted with respect to the reference group.

Creating Dummy Variables

Automatic Creation of Dummy Variables

The regression fitting functions, `LinearModel.fit`, `GeneralizedLinearModel.fit`, and `NonLinearModel.fit`, recognize categorical array inputs as categorical predictors. That is, if you input your categorical predictor as a `nominal` or `ordinal` array, the fitting function automatically creates the required dummy variables. The first level returned by `getlevels` is the reference group. To use a different reference group, use `reorderlevels` to change the level order.

If there are c unique levels in the categorical array, then the fitting function estimates $c - 1$ regression coefficients for the categorical predictor.

Note The fitting functions use every level of the categorical array returned by `getlevels`, even if there are levels with no observations. To remove levels from the categorical array, use `droplevels`.

Manual Creation of Dummy Variables

If you prefer to create your own dummy variable design matrix, use `dummyvar`. This function accepts a numeric or categorical column vector, and returns a matrix of indicator variables. The dummy variable design matrix has a column for every group, and a row for every observation.

For example,

```
gender = nominal({'Male'; 'Female'; 'Female'; 'Male'; 'Female'});
```

```
dv = dummyvar(gender)
```

```
dv =
```

```
    0    1
    1    0
    1    0
    0    1
    1    0
```

There are five rows corresponding to the number of rows in `gender`, and two columns for the unique groups, `Female` and `Male`. Column order corresponds to the order of the levels in `gender`. For nominal arrays, the default order is ascending alphabetical.

To use these dummy variables in a regression model, you must either delete a column (to create a reference group), or fit a regression model with no intercept term. For the gender example, only one dummy variable is needed to represent two genders. Notice what happens if you add an intercept term to the complete design matrix, `dv`.

```
X = [ones(5,1) dv]
```

```
X =
```

```
    1    0    1
    1    1    0
    1    1    0
    1    0    1
    1    1    0
```

```
rank(X)
```

```
ans =
```

```
    2
```

The design matrix with an intercept term is not of full rank, and is not invertible. Because of this linear dependence, use only $c - 1$ indicator variables to represent a categorical variable with c categories in a regression model with an intercept term.

See Also

[nominal](#) | [ordinal](#) | [LinearModel.fit](#) | [GeneralizedLinearModel.fit](#)
| [NonLinearModel.fit](#) | [dummyvar](#)

**Related
Examples**

- “Regression with Categorical Covariates” on page 2-80
- “Test Differences Between Category Means” on page 2-49

Regression with Categorical Covariates

This example shows how to perform a regression with categorical covariates using categorical arrays and `LinearModel.fit`.

Load sample data.

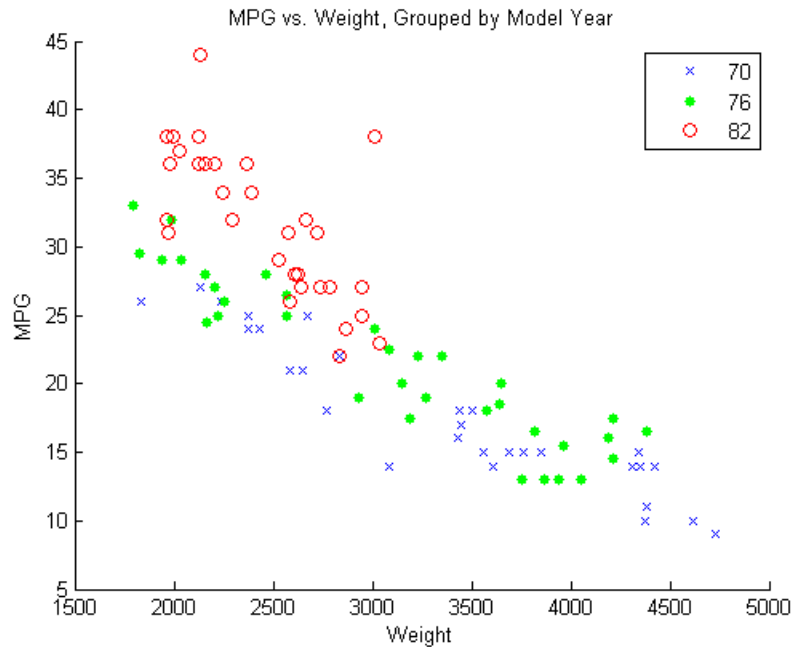
```
load('carsmall')
```

The variable `MPG` contains measurements on the miles per gallon of 100 sample cars. The model year of each car is in the variable `Model_Year`, and `Weight` contains the weight of each car.

Plot grouped data.

Draw a scatter plot of `MPG` against `Weight`, grouped by model year.

```
figure()  
gscatter(Weight,MPG,Model_Year,'bgr','x.o')  
title('MPG vs. Weight, Grouped by Model Year')
```

The grouping variable, `Model_Year`, has three unique values, 70, 76, and 82, corresponding to model years 1970, 1976, and 1982.

Create dataset and nominal arrays.

Create a dataset array that contains the variables `MPG`, `Weight`, and `Model_Year`.

```
cars = dataset(MPG,Weight,Model_Year);
```

Convert the variable `Model_Year` to a nominal array.

```
cars.Model_Year = nominal(cars.Model_Year);
```

Fit a regression model.

Fit a regression model using `LinearModel.fit` with `MPG` as the dependent variable, and `Weight` and `Model_Year` as the independent variables. Because `Model_Year` is a categorical covariate with three levels, it should enter the model as two indicator variables.

The scatter plot suggests that the slope of MPG against Weight might differ for each model year. To assess this, include weight-year interaction terms.

The proposed model is

$$E(MPG) = \beta_0 + \beta_1 Weight + \beta_2 I[1976] + \beta_3 I[1982] + \beta_4 Weight \times I[1976] + \beta_5 Weight \times I[1982]$$

where $I[1976]$ and $I[1982]$ indicate the model years 1976 and 1982, respectively. In this model, 1970 is the reference year.

```
fit = LinearModel.fit(cars, 'MPG~Weight*Model_Year')
```

```
fit =
```

```
Linear regression model:
```

```
MPG ~ 1 + Weight*Model_Year
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	37.399	2.1466	17.423	2.8607
Weight	-0.0058437	0.00061765	-9.4612	4.6077
Model_Year_76	4.6903	2.8538	1.6435	0.1
Model_Year_82	21.051	4.157	5.0641	2.2364
Weight:Model_Year_76	-0.00082009	0.00085468	-0.95953	0.3
Weight:Model_Year_82	-0.0050551	0.0015636	-3.2329	0.001

```
Number of observations: 94, Error degrees of freedom: 88
```

```
Root Mean Squared Error: 2.79
```

```
R-squared: 0.886, Adjusted R-Squared 0.88
```

```
F-statistic vs. constant model: 137, p-value = 5.79e-40
```

The regression output shows:

- `LinearModel.fit` recognizes `Model_Year` as a nominal variable, and constructs the required indicator (dummy) variables. By default, the first level, 70, is the reference group (use `reorderlevels` to change the reference group).
- The model specification, `MPG~Weight*Model_Year`, specifies the first-order terms for `Weight` and `Model_Year`, and all interactions.

- The model $R^2 = 0.886$, meaning the variation in miles per gallon is reduced by 88.6% when you consider weight, model year, and their interactions.
- The fitted model is

$$\hat{MPG} = 37.4 - 0.006Weight + 4.7I[1976] + 21.1I[1982] - 0.0008Weight \times I[1976] - 0.005Weight \times I[1982]$$

Thus, the estimated regression equations for the model years are as follows.

Model Year	Predicted MPG Against Weight
1970	$\hat{MPG} = 37.4 - 0.006Weight$
1976	$\hat{MPG} = (37.4 + 4.7) - (0.006 + 0.0008)Weight$
1982	$\hat{MPG} = (37.4 + 21.1) - (0.006 + 0.005)Weight$

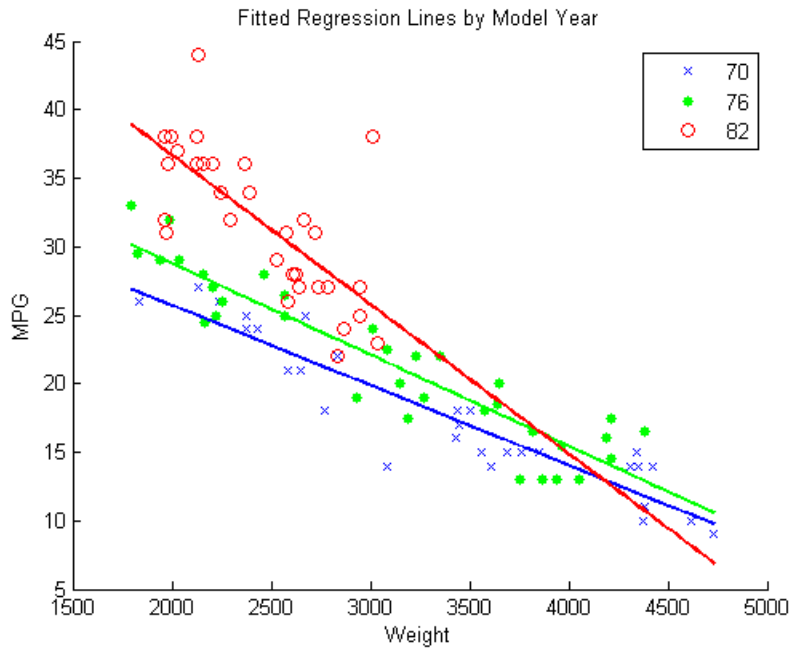
The relationship between MPG and Weight has an increasingly negative slope as the model year increases.

Plot fitted regression lines.

Plot the data and fitted regression lines.

```
w = linspace(min(Weight),max(Weight));

figure()
gscatter(Weight,MPG,Model_Year,'bgr','x.o')
line(w,feval(fit,w,'70'),'Color','b','LineWidth',2)
line(w,feval(fit,w,'76'),'Color','g','LineWidth',2)
line(w,feval(fit,w,'82'),'Color','r','LineWidth',2)
title('Fitted Regression Lines by Model Year')
```



Test for different slopes.

Test for significant differences between the slopes. This is equivalent to testing the hypothesis

$$H_0 : \beta_4 = \beta_5 = 0$$

$$H_A : \beta_i \neq 0 \text{ for at least one } i.$$

`anova(fit)`

ans =

	SumSq	DF	MeanSq	F	pValue
Weight	2050.2	1	2050.2	263.87	3.2055e-28
Model_Year	807.69	2	403.84	51.976	1.2494e-15
Weight:Model_Year	81.219	2	40.609	5.2266	0.0071637
Error	683.74	88	7.7698		

This output shows that the p -value for the test is 0.0072 (from the interaction row, `Weight:Model_Year`), so the null hypothesis is rejected at the 0.05 significance level. The value of the test statistic is 5.2266. The numerator degrees of freedom for the test is 2, which is the number of coefficients in the null hypothesis.

There is sufficient evidence that the slopes are not equal for all three model years.

See Also

`LinearModel.fit` | `dataset` | `nominal` | `reorderlevels` |

Related Examples

- “Plot Data Grouped by Category” on page 2-45
- “Test Differences Between Category Means” on page 2-49
- “Summary Statistics Grouped by Category” on page 2-58

Concepts

- “Advantages of Using Categorical Arrays” on page 2-64
- “Grouping Variables” on page 2-72
- “Dummy Indicator Variables” on page 2-76

Create a Dataset Array from Workspace Variables

In this section...

“Create a Dataset Array from a Numeric Array” on page 2-86

“Create Dataset Array from Heterogeneous Workspace Variables” on page 2-89

Create a Dataset Array from a Numeric Array

This example shows how to create a dataset array from a numeric array existing in the MATLAB workspace.

Load sample data.

```
load('fisheriris')
```

Two variables load into the workspace: `meas`, a 150-by-4 numeric array, and `species`, a 150-by-1 cell array of strings containing species labels.

Create a dataset array.

Use `mat2dataset` to convert the numeric array, `meas`, into a dataset array.

```
ds = mat2dataset(meas);  
ds(1:10,:)
```

```
ans =
```

meas1	meas2	meas3	meas4
5.1	3.5	1.4	0.2
4.9	3	1.4	0.2
4.7	3.2	1.3	0.2
4.6	3.1	1.5	0.2
5	3.6	1.4	0.2
5.4	3.9	1.7	0.4
4.6	3.4	1.4	0.3
5	3.4	1.5	0.2
4.4	2.9	1.4	0.2
4.9	3.1	1.5	0.1

The array, `meas`, has four columns, so the dataset array, `ds`, has four variables. The default variable names are the array name, `meas`, with column numbers appended.

You can specify your own variable or observation names using the name-value pair arguments `VarNames` and `ObsNames`, respectively.

If you use `dataset` to convert a numeric array to a dataset array, by default, the resulting dataset array has one variable that is an array instead of separate variables for each column.

Examine the dataset array.

Return the size of the dataset array, `ds`.

```
size(ds)
```

```
ans =
```

```
    150     4
```

The dataset array, `ds`, is the same size as the numeric array, `meas`. Variable names and observation names do not factor into the size of a dataset array.

Return the metadata properties of the dataset array, `ds`.

```
ds.Properties
```

```
ans =
```

```

    Description: ''
    VarDescription: {}
         Units: {}
    DimNames: {'Observations' 'Variables'}
    UserData: []
    ObsNames: {}
    VarNames: {'meas1' 'meas2' 'meas3' 'meas4'}
```

You can also access the properties individually. For example, you can retrieve the variable names and store them in a new variable, `names`.

```
names = ds.Properties.VarNames
names =
    'meas1'    'meas2'    'meas3'    'meas4'
```

Access data in a dataset array variable.

You can use variable names with dot indexing to access the data in a dataset array. For example, find the minimum value in the first variable, meas1.

```
min(ds.meas1)
ans =
    4.3000
```

Modify the dataset array.

The four variables in `ds` are actually measurements of sepal length, sepal width, petal length, and petal width. Modify the variable names to be more descriptive.

```
ds.Properties.VarNames = {'SLength', 'SWidth', 'PLength', 'PWidth'};
```

Additionally, you can add a description for the dataset array.

```
ds.Properties.Description = 'Fisher iris data';
ds.Properties
```

```
ans =
    Description: 'Fisher iris data'
    VarDescription: {}
    Units: {}
    DimNames: {'Observations' 'Variables'}
    UserData: []
    ObsNames: {}
    VarNames: {'SLength' 'SWidth' 'PLength' 'PWidth'}
```

The dataset array properties are updated with the new variable names and description.

Add a variable to the dataset array.

The variable `species` is a cell array of strings containing species labels. Add `species` to the dataset array, `ds`, as a nominal array named `Species`. Display the first five observations in the dataset array.

```
ds.Species = nominal(species);
ds(1:5,:)
```

```
ans =
```

SLength	SWidth	PLength	PWidth	Species
5.1	3.5	1.4	0.2	setosa
4.9	3	1.4	0.2	setosa
4.7	3.2	1.3	0.2	setosa
4.6	3.1	1.5	0.2	setosa
5	3.6	1.4	0.2	setosa

The dataset array, `ds`, now has the fifth variable, `Species`.

Create Dataset Array from Heterogeneous Workspace Variables

This example shows how to create a dataset array from heterogeneous variables existing in the MATLAB workspace.

Load sample data.

```
load('carsmall')
```

Create a dataset array.

Create a dataset array from a subset of the workspace variables.

```
ds = dataset(Origin,Acceleration,Cylinders,MPG);
ds.Properties.VarNames(:)
```

```
ans =
```

```
'Origin'
'Acceleration'
```

```
'Cylinders'  
'MPG'
```

When creating the dataset array, you do not need to enter variable names. `dataset` automatically uses the name of each workspace variable.

Notice that the dataset array, `ds`, contains a collection of variables with heterogeneous data types. `Origin` is a character array, and the other variables are numeric.

Examine a dataset array.

Display the first five observations in the dataset array.

```
ds(1:5,:)
```

```
ans =
```

Origin	Acceleration	Cylinders	MPG
USA	12	8	18
USA	11.5	8	15
USA	11	8	18
USA	12	8	16
USA	10.5	8	17

You can use `datasetfun` to return the data type of each variable in `ds`.

```
varclass = datasetfun(@class,ds,'UniformOutput',false);  
varclass(:)
```

```
ans =
```

```
'char'  
'double'  
'double'  
'double'
```

You can get additional information about the variables using `summary(ds)`.

Modify a dataset array.

`Cylinders` is a numeric variable that has values 4, 6, and 8 for the number of cylinders. Convert `Cylinders` to a nominal array with levels four, six, and eight.

```
ds.Cylinders = nominal(ds.Cylinders,{'four','six','eight'});
```

Display the country of origin and number of cylinders for the first 15 cars.

```
ds(1:15,{'Origin','Cylinders'})
```

```
ans =
```

Origin	Cylinders
USA	eight
USA	eight
USA	eight
USA	eight
USA	eight
USA	eight
USA	eight
USA	eight
USA	eight
USA	eight
USA	eight
France	four
USA	eight
USA	eight
USA	eight
USA	eight

The variable `Cylinders` has a new data type.

See Also

[dataset](#) | [datasetfun](#) | [mat2datasetnominal](#) |

Related Examples

- “Create a Dataset Array from a File” on page 2-92
- “Export Dataset Arrays” on page 2-136
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Create a Dataset Array from a File

In this section...

“Create a Dataset Array from a Tab-Delimited Text File” on page 2-92

“Create a Dataset Array from a Comma-Separated Text File” on page 2-95

“Create a Dataset Array from an Excel File” on page 2-98

Create a Dataset Array from a Tab-Delimited Text File

This example shows how to create a dataset array from the contents of a tab-delimited text file.

Create a dataset array using default settings.

Navigate to the folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the text file `hospitalSmall.txt` as a dataset array using the default settings.

```
ds = dataset('File','hospitalSmall.txt')
```

```
ds =
```

name	sex	age	wgt	smoke
'SMITH'	'm'	38	176	1
'JOHNSON'	'm'	43	163	0
'WILLIAMS'	'f'	38	131	0
'JONES'	'f'	40	133	0
'BROWN'	'f'	49	119	0
'DAVIS'	'f'	46	142	0
'MILLER'	'f'	33	142	1
'WILSON'	'm'	40	180	0
'MOORE'	'm'	28	183	0
'TAYLOR'	'f'	31	132	0
'ANDERSON'	'f'	45	128	0
'THOMAS'	'f'	42	137	0

```
'JACKSON'      'm'      25      174      0
'WHITE'        'm'      39      202      1
```

By default, `dataset` uses the first row of the text file for variable names. If the first row does not contain variable names, you can specify the optional name-value pair argument `'ReadVarNames', false` to change the default behavior.

The dataset array contains heterogeneous variables. The variables `id`, `name`, and `sex` are cell arrays of strings, and the other variables are numeric. You can see the data type and other descriptive statistics for each variable by using `summary` to summarize the dataset array.

```
summary(ds)
```

```
name: [14x1 cell string]
```

```
sex: [14x1 cell string]
```

```
age: [14x1 double]
```

min	1st quartile	median	3rd quartile	max
25	33	39.5	43	49

```
wgt: [14x1 double]
```

min	1st quartile	median	3rd quartile	max
119	132	142	176	202

```
smoke: [14x1 double]
```

min	1st quartile	median	3rd quartile	max
0	0	0	0	1

Import observation names.

Import the text file again, this time specifying that the first column contains observation names.

```
ds = dataset('File','hospitalSmall.txt','ReadObsNames',true)
```

```
ds =  
  
      sex      age  wgt  smoke  
SMITH  'm'      38  176   1  
JOHNSON 'm'      43  163   0  
WILLIAMS 'f'      38  131   0  
JONES   'f'      40  133   0  
BROWN   'f'      49  119   0  
DAVIS   'f'      46  142   0  
MILLER  'f'      33  142   1  
WILSON  'm'      40  180   0  
MOORE   'm'      28  183   0  
TAYLOR  'f'      31  132   0  
ANDERSON 'f'      45  128   0  
THOMAS  'f'      42  137   0  
JACKSON 'm'      25  174   0  
WHITE   'm'      39  202   1
```

The elements of the first column in the text file, last names, are now observation names. Observation names and row names are dataset array properties.

`ds.Properties`

```
ans =  
  
Description: ''  
VarDescription: {}  
Units: {}  
DimNames: {'name' 'Variables'}  
UserData: []  
ObsNames: {14x1 cell}  
VarNames: {'sex' 'age' 'wgt' 'smoke'}
```

You can always add or change the observation names of an existing dataset array by modifying the property `ObsNames`.

Notice that the `DimNames` property has `name` as the descriptor of the observation (row) dimension. `dataset` got this name from the first row of the first column in the text file.

Change the first element of `DimNames` to `LastName`.

```
ds.Properties.DimNames{1} = 'LastName';
ds.Properties
```

```
ans =
```

```

    Description: ''
  VarDescription: {}
         Units: {}
    DimNames: {'LastName' 'Variables'}
    UserData: []
    ObsNames: {14x1 cell}
    VarNames: {'sex' 'age' 'wgt' 'smoke'}
```

You can use observation names to index into a dataset array. For example, return the data for the patient with last name `BROWN`.

```
ds('BROWN', :)
```

```
ans =
```

```

           sex      age      wgt      smoke
    BROWN    'f'      49      119      0
```

Observation names must be unique.

Create a Dataset Array from a Comma-Separated Text File

This example shows how to create a dataset array from the contents of a comma-separated text file.

Create a dataset array.

Navigate to the folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the file `hospitalSmall.csv` as a dataset array, specifying the comma-delimited format.

```
ds = dataset('File','hospitalSmall.csv','Delimiter',',',')
```

```
ds =
```

id	name	sex	age	wgt	smoke
'YPL-320'	'SMITH'	'm'	38	176	1
'GLI-532'	'JOHNSON'	'm'	43	163	0
'PNI-258'	'WILLIAMS'	'f'	38	131	0
'MIJ-579'	'JONES'	'f'	40	133	0
'XLK-030'	'BROWN'	'f'	49	119	0
'TFP-518'	'DAVIS'	'f'	46	142	0
'LPD-746'	'MILLER'	'f'	33	142	1
'ATA-945'	'WILSON'	'm'	40	180	0
'VNL-702'	'MOORE'	'm'	28	183	0
'LQW-768'	'TAYLOR'	'f'	31	132	0
'QFY-472'	'ANDERSON'	'f'	45	128	0
'UJG-627'	'THOMAS'	'f'	42	137	0
'XUE-826'	'JACKSON'	'm'	25	174	0
'TRW-072'	'WHITE'	'm'	39	202	1

By default, `dataset` uses the first row in the text file as variable names.

Add observation names.

Use the unique identifiers in the variable `id` as observation names. Then, delete the variable `id` from the dataset array.

```
ds.Properties.ObsNames = ds.id;
```

```
ds.id = []
```

```
ds =
```

	name	sex	age	wgt	smoke
YPL-320	'SMITH'	'm'	38	176	1
GLI-532	'JOHNSON'	'm'	43	163	0
PNI-258	'WILLIAMS'	'f'	38	131	0
MIJ-579	'JONES'	'f'	40	133	0
XLK-030	'BROWN'	'f'	49	119	0

TFP-518	'DAVIS'	'f'	46	142	0
LPD-746	'MILLER'	'f'	33	142	1
ATA-945	'WILSON'	'm'	40	180	0
VNL-702	'MOORE'	'm'	28	183	0
LQW-768	'TAYLOR'	'f'	31	132	0
QFY-472	'ANDERSON'	'f'	45	128	0
UJG-627	'THOMAS'	'f'	42	137	0
XUE-826	'JACKSON'	'm'	25	174	0
TRW-072	'WHITE'	'm'	39	202	1

Delete observations.

Delete any patients with the last name BROWN. You can use `strcmp` to match the string 'BROWN' with the elements of the variable containing last names, `name`.

```
toDelete = strcmp(ds.name, 'BROWN');
ds(toDelete,:) = []
```

```
ds =
```

	name	sex	age	wgt	smoke
YPL-320	'SMITH'	'm'	38	176	1
GLI-532	'JOHNSON'	'm'	43	163	0
PNI-258	'WILLIAMS'	'f'	38	131	0
MIJ-579	'JONES'	'f'	40	133	0
TFP-518	'DAVIS'	'f'	46	142	0
LPD-746	'MILLER'	'f'	33	142	1
ATA-945	'WILSON'	'm'	40	180	0
VNL-702	'MOORE'	'm'	28	183	0
LQW-768	'TAYLOR'	'f'	31	132	0
QFY-472	'ANDERSON'	'f'	45	128	0
UJG-627	'THOMAS'	'f'	42	137	0
XUE-826	'JACKSON'	'm'	25	174	0
TRW-072	'WHITE'	'm'	39	202	1

One patient having last name BROWN is deleted from the dataset array. The array now has 13 observations:

```
size(ds)
```

```
ans =  
  
    13     5
```

Note that the row and column corresponding to variable and observation names, respectively, are not included in the size of a dataset array.

Create a Dataset Array from an Excel File

This example shows how to create a dataset array from the contents of an Excel® spreadsheet file.

Create a dataset array.

Navigate to the folder containing sample data.

```
cd(matlabroot)  
cd('help/toolbox/stats/examples')
```

Import the data from the first worksheet in the file `hospitalSmall.xlsx`, specifying that the data file is an Excel spreadsheet.

```
ds = dataset('XLSFile','hospitalSmall.xlsx')
```

```
ds =  
  
    id          name          sex      age    wgt  smoke  
    'YPL-320'    'SMITH'      'm'     38    176     1  
    'GLI-532'    'JOHNSON'    'm'     43    163     0  
    'PNI-258'    'WILLIAMS'   'f'     38    131     0  
    'MIJ-579'    'JONES'      'f'     40    133     0  
    'XLK-030'    'BROWN'      'f'     49    119     0  
    'TFP-518'    'DAVIS'      'f'     46    142     0  
    'LPD-746'    'MILLER'     'f'     33    142     1  
    'ATA-945'    'WILSON'     'm'     40    180     0  
    'VNL-702'    'MOORE'      'm'     28    183     0  
    'LQW-768'    'TAYLOR'     'f'     31    132     0  
    'QFY-472'    'ANDERSON'   'f'     45    128     0  
    'UJG-627'    'THOMAS'     'f'     42    137     0  
    'XUE-826'    'JACKSON'    'm'     25    174     0  
    'TRW-072'    'WHITE'      'm'     39    202     1
```

By default, `dataset` creates variable names using the contents of the first row in the spreadsheet.

Specify which worksheet to import.

Import the data from the second worksheet into a new dataset array.

```
ds2 = dataset('XLSFile', 'hospitalSmall.xlsx', 'Sheet', 2)
```

```
ds2 =
```

id	name	sex	age	wgt	smoke
'TRW-072'	'WHITE'	'm'	39	202	1
'ELG-976'	'HARRIS'	'f'	36	129	0
'KOQ-996'	'MARTIN'	'm'	48	181	1
'YUZ-646'	'THOMPSON'	'm'	32	191	1
'XBR-291'	'GARCIA'	'f'	27	131	1
'KPW-846'	'MARTINEZ'	'm'	37	179	0
'XBA-581'	'ROBINSON'	'm'	50	172	0
'BKD-785'	'CLARK'	'f'	48	133	0

See Also

[dataset](#) | [summary](#) |

Related Examples

- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Clean Messy and Missing Data” on page 2-138
- “Export Dataset Arrays” on page 2-136
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Add and Delete Observations

This example shows how to add and delete observations in a dataset array. You can also edit dataset arrays using the Variables editor.

Load sample data.

Navigate to the folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the data from the first worksheet in `hospitalSmall.xlsx` into a dataset array.

```
ds = dataset('XLSFile','hospitalSmall.xlsx');
size(ds)
```

```
ans =
```

```
    14     6
```

The dataset array, `ds`, has 14 observations (rows) and 6 variables (columns).

Add observations by concatenation.

The second worksheet in `hospitalSmall.xlsx` has additional patient data. Append the observations in this spreadsheet to the end of `ds`.

```
ds2 = dataset('XLSFile','hospitalSmall.xlsx','Sheet',2);
dsNew = [ds;ds2];
size(dsNew)
```

```
ans =
```

```
    22     6
```

The dataset array `dsNew` has 22 observations. In order to vertically concatenate two dataset arrays, both arrays must have the same number of variables, with the same variable names.

Add observations from a cell array.

If you want to append new observations stored in a cell array, first convert the cell array to a dataset array, and then concatenate the dataset arrays.

```
cellObs = {'id', 'name', 'sex', 'age', 'wgt', 'smoke';
           'YQR-965', 'BAKER', 'M', 36, 160, 0;
           'LFG-497', 'WALL', 'F', 28, 125, 1;
           'KSD-003', 'REED', 'M', 32, 187, 0};
dsNew = [dsNew; cell2dataset(cellObs)];
size(dsNew)
```

```
ans =
```

```
    25     6
```

Add observations from a structure.

You can also append new observations stored in a structure. Convert the structure to a dataset array, and then concatenate the dataset arrays.

```
structObs(1,1).id = 'GHK-842';
structObs(1,1).name = 'GEORGE';
structObs(1,1).sex = 'M';
structObs(1,1).age = 45;
structObs(1,1).wgt = 182;
structObs(1,1).smoke = 1;

structObs(2,1).id = 'QRH-308';
structObs(2,1).name = 'BAILEY';
structObs(2,1).sex = 'F';
structObs(2,1).age = 29;
structObs(2,1).wgt = 120;
structObs(2,1).smoke = 0;

dsNew = [dsNew; struct2dataset(structObs)];
size(dsNew)
```

```
ans =
```

```
    27     6
```

Delete duplicate observations.

Use `unique` to delete any observations in a dataset array that are duplicated.

```
dsNew = unique(dsNew);  
size(dsNew)
```

```
ans =  
  
    21     6
```

One duplicated observation is deleted.

Delete observations by observation number.

Delete observations 18, 20, and 21 from the dataset array.

```
dsNew([18,20,21],:) = [];  
size(dsNew)
```

```
ans =  
  
    18     6
```

The dataset array has only 18 observations now.

Delete observations by observation name.

First, specify the variable of identifiers, `id`, as observation names. Then, delete the variable `id` from `dsNew`. You can use the observation name to index observations.

```
dsNew.Properties.ObsNames = dsNew.id;  
dsNew.id = [];  
dsNew('K0Q-996',:) = [];  
size(dsNew)
```

```
ans =  
  
    17     5
```

The dataset array now has one less observation and one less variable.

Search for observations to delete.

You can also search for observations in the dataset array. For example, delete observations for any patients with the last name WILLIAMS.

```
toDelete = strcmp(dsNew.name, 'WILLIAMS');  
dsNew(toDelete,:) = [];  
size(dsNew)
```

```
ans =
```

```
    16     5
```

The dataset array now has one less observation.

See Also

[dataset](#) | [cell2dataset](#) | [struct2dataset](#)

Related Examples

- “Add and Delete Variables” on page 2-104
- “Select Subsets of Observations” on page 2-114
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Add and Delete Variables

This example shows how to add and delete variables in a dataset array. You can also edit dataset arrays using the Variables editor.

Load sample data.

Navigate to the folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the data from the first worksheet in `hospitalSmall.xlsx` into a dataset array.

```
ds = dataset('XLSFile','hospitalSmall.xlsx');
size(ds)
```

```
ans =
```

```
    14     6
```

The dataset array, `ds`, has 14 observations (rows) and 6 variables (columns).

Add variables by concatenating dataset arrays.

The worksheet `Heights` in `hospitalSmall.xlsx` has heights for the patients on the first worksheet. Concatenate the data in this spreadsheet with `ds`.

```
ds2 = dataset('XLSFile','hospitalSmall.xlsx','Sheet','Heights');
ds = [ds ds2];
size(ds)
```

```
ans =
```

```
    14     7
```

The dataset array now has seven variables. You can only horizontally concatenate dataset arrays with observations in the same position, or with the same observation names.

```
ds.Properties.VarNames{end}
```



```
ans =
```

```
hgt
```

The name of the last variable in `ds` is `hgt`, which dataset read from the first row of the imported spreadsheet.

Delete variables by variable name.

First, specify the unique identifiers in the variable `id` as observation names. Then, delete the variable `id` from the dataset array.

```
ds.Properties.ObsNames = ds.id;
ds.id = [];
size(ds)
```

```
ans =
```

```
14    6
```

The dataset array now has six variables. List the variable names.

```
ds.Properties.VarNames(:)
```

```
ans =
```

```
'name'
'sex'
'age'
'wgt'
'smoke'
'hgt'
```

There is no longer a variable called `id`.

Add a new variable by name.

Add a new variable, `bmi`—which contains the body mass index (BMI) for each patient—to the dataset array. BMI is a function of height and weight. Display the last name, gender, and BMI for each patient.

```
ds.bmi = ds.wgt*703./ds.hgt.^2;
```

```
ds(:, {'name', 'sex', 'bmi'})
```

```
ans =
```

	name	sex	bmi
YPL-320	'SMITH'	'm'	24.544
GLI-532	'JOHNSON'	'm'	24.068
PNI-258	'WILLIAMS'	'f'	23.958
MIJ-579	'JONES'	'f'	25.127
XLK-030	'BROWN'	'f'	21.078
TFP-518	'DAVIS'	'f'	27.729
LPD-746	'MILLER'	'f'	26.828
ATA-945	'WILSON'	'm'	24.41
VNL-702	'MOORE'	'm'	27.822
LQW-768	'TAYLOR'	'f'	22.655
QFY-472	'ANDERSON'	'f'	23.409
UJG-627	'THOMAS'	'f'	25.883
XUE-826	'JACKSON'	'm'	24.265
TRW-072	'WHITE'	'm'	29.827

The operators `./` and `.^` in the calculation of BMI indicate element-wise division and exponentiation, respectively.

Delete variables by variable number.

Delete the variable `wgt`, the fourth variable in the dataset array.

```
ds(:,4) = [];  
ds.Properties.VarNames(:)
```

```
ans =
```

```
'name'  
'sex'  
'age'  
'smoke'  
'hgt'  
'bmi'
```

The variable `wgt` is deleted from the dataset array.

See Also dataset |

**Related
Examples**

- “Add and Delete Observations” on page 2-100
- “Merge Dataset Arrays” on page 2-122
- “Calculations on Dataset Arrays” on page 2-132
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Access Data in Dataset Array Variables

This example shows how to work with dataset array variables and their data.

Access variables by name.

You can access variable data, or select a subset of variables, by using variable (column) names and dot indexing. Load a sample dataset array.

```
load('hospital')
```

The dataset array has 7 variables (columns) and 100 observations (rows). You can double-click `hospital` in the Workspace window to view the dataset array in the Variables editor.

Display the names of the variables in `hospital`.

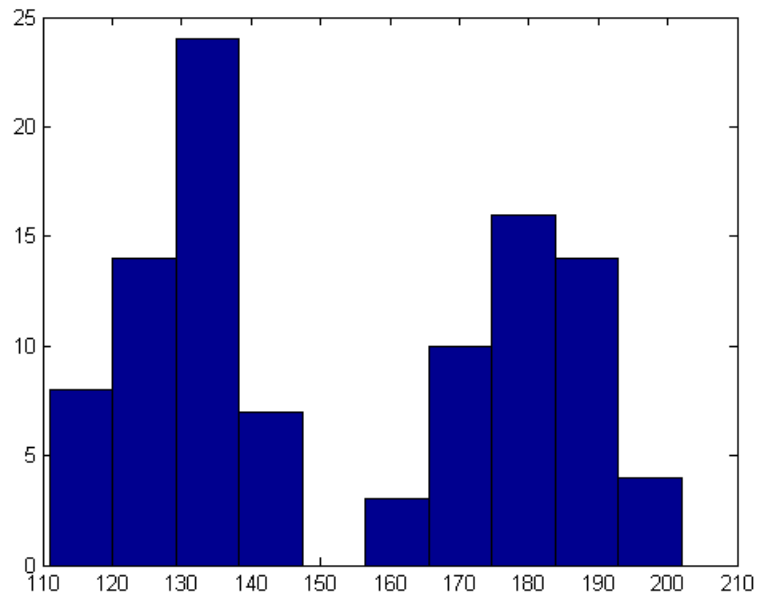
```
hospital.Properties.VarNames(:)
```

```
ans =
```

```
    'LastName'  
    'Sex'  
    'Age'  
    'Weight'  
    'Smoker'  
    'BloodPressure'  
    'Trials'
```

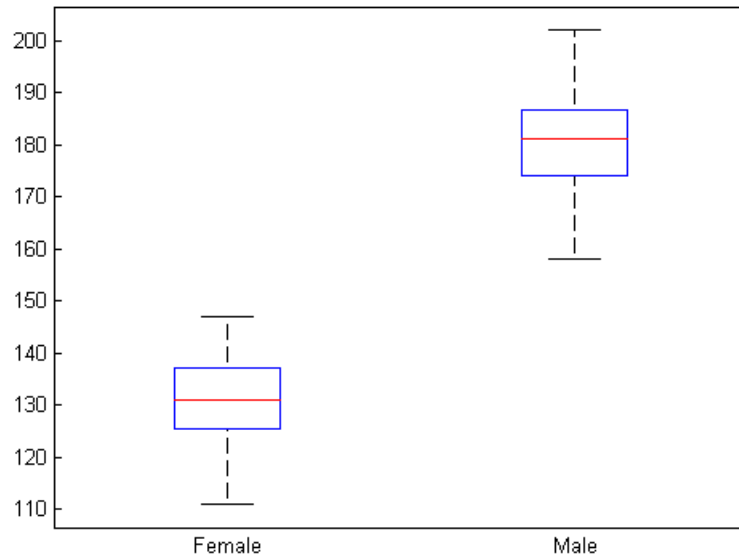
Plot a histogram of the data in the variable `Weight`.

```
figure()  
hist(hospital.Weight)
```



The histogram shows that the weight distribution is bimodal. Draw box plots of `Weight` grouped by the values in `Sex` (Male and Female). That is, use the variable `Sex` as a grouping variable.

```
figure()  
boxplot(hospital.Weight,hospital.Sex)
```



The box plot suggests that gender accounts for the bimodality in weight.

Select a subset of variables.

Create a new dataset array with only the variables `LastName`, `Sex`, and `Weight`. You can access the variables by name or column number.

```
ds1 = hospital(:, {'LastName', 'Sex', 'Weight'});  
ds2 = hospital(:, [1, 2, 4]);
```

The dataset arrays `ds1` and `ds2` are equivalent. Use parentheses () when indexing dataset arrays to preserve the data type; that is, to create a dataset array from a subset of a dataset array. You can also use the Variables editor to create a new dataset array from a subset of variables and observations.

Convert the variable data type.

Convert the data type of the variable `Smoker` from logical to nominal with labels `No` and `Yes`.

```
class(hospital.Smoker)

ans =

logical

hospital.Smoker = nominal(hospital.Smoker,{'No','Yes'});
class(hospital.Smoker)

ans =

nominal

Display the first 10 elements of Smoker.

hospital.Smoker(1:10)

ans =

    Yes
    No
    No
    No
    No
    No
    Yes
    No
    No
    No
```

If you want to change the level labels in a nominal array, use `setlabels`.

Add variables.

The variable `BloodPressure` is a 100-by-2 array. The first column corresponds to systolic blood pressure, and the second column to diastolic blood pressure. Separate this array into two new variables, `SysPressure` and `DiaPressure`.

```
size(hospital.BloodPressure)

ans =
```

```
100      2
```

```
hospital.SysPressure = hospital.BloodPressure(:,1);  
hospital.DiaPressure = hospital.BloodPressure(:,2);  
hospital.Properties.VarNames(:)
```

```
ans =
```

```
'LastName'  
'Sex'  
'Age'  
'Weight'  
'Smoker'  
'BloodPressure'  
'Trials'  
'SysPressure'  
'DiaPressure'
```

The dataset array, `hospital`, has two new variables.

Search for variables by name.

Use `regexp` to find variables in `hospital` with the string 'Pressure' in their name. Create a new dataset array containing only these variables.

```
bp = regexp(hospital.Properties.VarNames, 'Pressure');  
bpIdx = cellfun(@isempty, bp);  
bpData = hospital(:, ~bpIdx);  
bpData.Properties.VarNames(:)
```

```
ans =
```

```
'BloodPressure'  
'SysPressure'  
'DiaPressure'
```

The new dataset array, `bpData`, contains only the blood pressure variables.

Delete variables.

Delete the variable `BloodPressure` from the dataset array, `hospital`.


```
hospital.BloodPressure = [];  
hospital.Properties.VarNames(:)
```

```
ans =  
  
    'LastName'  
    'Sex'  
    'Age'  
    'Weight'  
    'Smoker'  
    'Trials'  
    'SysPressure'  
    'DiaPressure'
```

The variable `BloodPressure` is no longer in the dataset array.

See Also `dataset` |

Related Examples

- “Add and Delete Variables” on page 2-104
- “Calculations on Dataset Arrays” on page 2-132
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156
- “Grouping Variables” on page 2-72

Select Subsets of Observations

This example shows how to select an observation or subset of observations from a dataset array.

Index observations by name.

Load the sample dataset array, `hospital`. Dataset arrays can have observation (row) names. This array has observation names corresponding to unique patient identifiers.

```
load('hospital')
hospital.Properties.ObsNames(1:10)
```

```
ans =
```

```
'YPL-320'
'GLI-532'
'PNI-258'
'MIJ-579'
'XLK-030'
'TFP-518'
'LPD-746'
'ATA-945'
'VNL-702'
'LQW-768'
```

These are the first 10 observation names. You can use them to index into the dataset array. For example, extract the last name, sex, and age for the patient with identifier `XLK-030`.

```
hospital('XLK-030',{'LastName','Sex','Age'})
```

```
ans =
```

	LastName	Sex	Age
XLK-030	'BROWN'	Female	49

Index a subset of observations by number.

Create a new dataset array containing the first 50 patients.

```
ds50 = hospital(1:50,:);
size(ds50)
```

```
ans =
```

```
50    7
```

Search observations using a logical condition.

Create a new dataset array containing only male patients. To find the male patients, use a logical condition to search the variable containing gender information.

```
dsMale = hospital(hospital.Sex=='Male',:);
dsMale(1:10,{'LastName','Sex'})
```

```
ans =
```

	LastName	Sex
YPL-320	'SMITH'	Male
GLI-532	'JOHNSON'	Male
ATA-945	'WILSON'	Male
VNL-702	'MOORE'	Male
XUE-826	'JACKSON'	Male
TRW-072	'WHITE'	Male
KOQ-996	'MARTIN'	Male
YUZ-646	'THOMPSON'	Male
KPW-846	'MARTINEZ'	Male
XBA-581	'ROBINSON'	Male

You can use multiple conditions to search the dataset array. For example, create a new dataset array containing only female patients older than 40.

```
dsFemale = hospital(hospital.Sex=='Female' & hospital.Age > 40,:);
dsFemale(1:10,{'LastName','Sex','Age'})
```

```
ans =
```

	LastName	Sex	Age
XLK-030	'BROWN'	Female	49
TFP-518	'DAVIS'	Female	46

QFY-472	'ANDERSON'	Female	45
UJG-627	'THOMAS'	Female	42
BKD-785	'CLARK'	Female	48
VWL-936	'LEWIS'	Female	41
AAX-056	'LEE'	Female	44
AFK-336	'WRIGHT'	Female	45
KKL-155	'ADAMS'	Female	48
RBA-579	'SANCHEZ'	Female	44

Select a random subset of observations.

Create a new dataset array containing a random subset of 20 patients from the dataset array `hospital`.

```
rng('default') % For reproducibility
dsRandom = hospital(randsample(length(hospital),20),:);
dsRandom.Properties.ObsNames
```

```
ans =
```

```
'DAU-529'
'AGR-528'
'RBO-332'
'Q00-305'
'RVS-253'
'QEQ-082'
'EHE-616'
'HVR-372'
'KOQ-996'
'REV-997'
'PUE-347'
'LQW-768'
'YLN-495'
'HJQ-495'
'ELG-976'
'XUE-826'
'MEZ-469'
'UDS-151'
'MIJ-579'
'DGC-290'
```

Delete observations by name.

Delete the data for the patient with observation name HVR-372.

```
hospital('HVR-372',:) = [];  
size(hospital)
```

```
ans =
```

```
    99     7
```

The dataset array has one less observation.

See Also [dataset](#) |**Related Examples**

- “Add and Delete Observations” on page 2-100
- “Clean Messy and Missing Data” on page 2-138
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Sort Observations in Dataset Arrays” on page 2-118
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Sort Observations in Dataset Arrays

This example shows how to sort observations (rows) in a dataset array using the command line. You can also sort rows using the Variables editor.

Sort observations by the values of a single variable.

Load the sample dataset array, `hospital`. Sort the observations by the values in `Age`, in ascending order.

```
load('hospital')
dsAgeUp = sortrows(hospital,'Age');
dsAgeUp(1:10,{'LastName','Age'})

ans =
```

	LastName	Age
XUE-826	'JACKSON'	25
FZR-250	'HALL'	25
PUE-347	'YOUNG'	25
LIM-480	'HILL'	25
SCQ-914	'JAMES'	25
REV-997	'ALEXANDER'	25
XBR-291	'GARCIA'	27
VNL-702	'MOORE'	28
DTT-578	'WALKER'	28
XAX-646	'COOPER'	28

The youngest patients are age 25.

Sort the observations by `Age` in descending order.

```
dsAgeDown = sortrows(hospital,'Age','descend');
dsAgeDown(1:10,{'LastName','Age'})

ans =
```

	LastName	Age
XBA-581	'ROBINSON'	50
DAU-529	'REED'	50
XLK-030	'BROWN'	49

FLJ-908	'STEWART'	49
GGU-691	'HUGHES'	49
MEZ-469	'GRIFFIN'	49
KOQ-996	'MARTIN'	48
BKD-785	'CLARK'	48
KKL-155	'ADAMS'	48
NSK-403	'RAMIREZ'	48

The oldest patients are age 50.

Sort observations by the values of two variables.

Sort the observations in hospital by Age, and then by LastName.

```
dsName = sortrows(hospital,{'Age','LastName'});
dsName(1:10,{'LastName','Age'})
```

ans =

	LastName	Age
REV-997	'ALEXANDER'	25
FZR-250	'HALL'	25
LIM-480	'HILL'	25
XUE-826	'JACKSON'	25
SCQ-914	'JAMES'	25
PUE-347	'YOUNG'	25
XBR-291	'GARCIA'	27
XAX-646	'COOPER'	28
QEQ-082	'COX'	28
NSU-424	'JENKINS'	28

Now the names are sorted alphabetically within increasing age groups.

Sort the observations in hospital by Age in an increasing order, and then by Weight in a decreasing order.

```
dsWeight = sortrows(hospital,{'Age','Weight'},{'ascend','descend'});
dsWeight(1:10,{'LastName','Age','Weight'})
```

ans =

	LastName	Age	Weight
FZR-250	'HALL'	25	189
SCQ-914	'JAMES'	25	186
XUE-826	'JACKSON'	25	174
REV-997	'ALEXANDER'	25	171
LIM-480	'HILL'	25	138
PUE-347	'YOUNG'	25	114
XBR-291	'GARCIA'	27	131
NSU-424	'JENKINS'	28	189
VNL-702	'MOORE'	28	183
XAX-646	'COOPER'	28	127

This shows that the maximum weight among patients that are age 25 is 189 lbs.

Sort observations by observation name.

Sort the observations in hospital by the observation names.

```
dsObs = sortrows(hospital, 'obsnames');  
dsObs(1:10, {'LastName', 'Age'})
```

```
ans =
```

	LastName	Age
AAX-056	'LEE'	44
AFB-271	'PEREZ'	44
AFK-336	'WRIGHT'	45
AGR-528	'SIMMONS'	45
ATA-945	'WILSON'	40
BEZ-311	'DIAZ'	45
BKD-785	'CLARK'	48
DAU-529	'REED'	50
DGC-290	'BUTLER'	38
DTT-578	'WALKER'	28

The observations are sorted by observation name in ascending alphabetical order.

See Also

[dataset](#) | [sortrows](#) |

**Related
Examples**

- “Select Subsets of Observations” on page 2-114
- “Stack or Unstack Dataset Arrays” on page 2-127
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Merge Dataset Arrays

This example shows how to merge dataset arrays using `join`.

Load sample data.

Navigate to a folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the data from the first worksheet in `hospitalSmall.xlsx` into a dataset array, then keep only a few of the variables.

```
ds1 = dataset('XLSFile','hospitalSmall.xlsx');
ds1 = ds1(:,{'id','name','sex','age'})
```

```
ds1 =
```

id	name	sex	age
'YPL-320'	'SMITH'	'm'	38
'GLI-532'	'JOHNSON'	'm'	43
'PNI-258'	'WILLIAMS'	'f'	38
'MIJ-579'	'JONES'	'f'	40
'XLK-030'	'BROWN'	'f'	49
'TFP-518'	'DAVIS'	'f'	46
'LPD-746'	'MILLER'	'f'	33
'ATA-945'	'WILSON'	'm'	40
'VNL-702'	'MOORE'	'm'	28
'LQW-768'	'TAYLOR'	'f'	31
'QFY-472'	'ANDERSON'	'f'	45
'UJG-627'	'THOMAS'	'f'	42
'XUE-826'	'JACKSON'	'm'	25
'TRW-072'	'WHITE'	'm'	39

The dataset array, `ds1`, has 14 observations (rows) and 4 variables (columns).

Import the data from the worksheet `Heights2` in `hospitalSmall.xlsx`.

```
ds2 = dataset('XLSFile','hospitalSmall.xlsx','Sheet','Heights2')
```

```
ds2 =
```

id	hgt
'LPD-746'	61
'PNI-258'	62
'XUE-826'	71
'ATA-945'	72
'XLK-030'	63

ds2 has height measurements for a subset of five individuals from the first dataset array, ds1.

Merge only the matching subset of observations.

Use `join` to merge the two dataset arrays, ds1 and ds2, keeping only the subset of observations that are in ds2.

```
JoinSmall = join(ds2,ds1)
```

```
JoinSmall =
```

id	hgt	name	sex	age
'LPD-746'	61	'MILLER'	'f'	33
'PNI-258'	62	'WILLIAMS'	'f'	38
'XUE-826'	71	'JACKSON'	'm'	25
'ATA-945'	72	'WILSON'	'm'	40
'XLK-030'	63	'BROWN'	'f'	49

In `JoinSmall`, the variable `id` only appears once. This is because it is the key variable—the variable that links observations between the two dataset arrays—and has the same variable name in both `ds1` and `ds2`.

Include incomplete observations in the merge.

Merge `ds1` and `ds2` keeping all observations in the larger `ds1`.

```
joinAll = join(ds2,ds1,'type','rightouter','mergekeys',true)
```

```
joinAll =
```

id	hgt	name	sex	age
----	-----	------	-----	-----

'ATA-945'	72	'WILSON'	'm'	40
'GLI-532'	NaN	'JOHNSON'	'm'	43
'LPD-746'	61	'MILLER'	'f'	33
'LQW-768'	NaN	'TAYLOR'	'f'	31
'MIJ-579'	NaN	'JONES'	'f'	40
'PNI-258'	62	'WILLIAMS'	'f'	38
'QFY-472'	NaN	'ANDERSON'	'f'	45
'TFP-518'	NaN	'DAVIS'	'f'	46
'TRW-072'	NaN	'WHITE'	'm'	39
'UJG-627'	NaN	'THOMAS'	'f'	42
'VNL-702'	NaN	'MOORE'	'm'	28
'XLK-030'	63	'BROWN'	'f'	49
'XUE-826'	71	'JACKSON'	'm'	25
'YPL-320'	NaN	'SMITH'	'm'	38

Each observation in `ds1` without corresponding height measurements in `ds2` has height value `NaN`. Also, because there is no `id` value in `ds2` for each observation in `ds1`, you need to merge the keys using the option `'MergeKeys', true`. This merges the key variable, `id`.

Merge dataset arrays with different key variable names.

When using `join`, it is not necessary for the key variable to have the same name in the dataset arrays to be merged. Import the data from the worksheet named `Heights3` in `hospitalSmall.xlsx`.

```
ds3 = dataset('XLSFile', 'hospitalSmall.xlsx', 'Sheet', 'Heights3')
```

```
ds3 =
```

identifier	hgt
'GLI-532'	69
'QFY-472'	62
'MIJ-579'	61
'VNL-702'	68
'XLK-030'	63
'LPD-746'	61
'TFP-518'	60
'YPL-320'	71
'ATA-945'	72
'LQW-768'	64

```
'PNI-258'      62
'UJG-627'      61
'XUE-826'      71
'TRW-072'      69
```

`ds3` has height measurements for each observation in `ds1`. This dataset array has the same patient identifiers as `ds1`, but they are under the variable name `identifier`, instead of `id` (and in a different order).

You can easily change the variable name of the key variable in `ds3` by setting `d3.Properties.VarNames` or using the Variables editor, but it is not required to perform a merge. Instead, you can specify the name of the key variable in each dataset array using `LeftKeys` and `RightKeys`.

```
joinDiff = join(ds3,ds1,'LeftKeys','identifier','RightKeys','id')
```

```
joinDiff =
```

identifier	hgt	name	sex	age
'GLI-532'	69	'JOHNSON'	'm'	43
'QFY-472'	62	'ANDERSON'	'f'	45
'MIJ-579'	61	'JONES'	'f'	40
'VNL-702'	68	'MOORE'	'm'	28
'XLK-030'	63	'BROWN'	'f'	49
'LPD-746'	61	'MILLER'	'f'	33
'TFP-518'	60	'DAVIS'	'f'	46
'YPL-320'	71	'SMITH'	'm'	38
'ATA-945'	72	'WILSON'	'm'	40
'LQW-768'	64	'TAYLOR'	'f'	31
'PNI-258'	62	'WILLIAMS'	'f'	38
'UJG-627'	61	'THOMAS'	'f'	42
'XUE-826'	71	'JACKSON'	'm'	25
'TRW-072'	69	'WHITE'	'm'	39

The merged dataset array, `joinDiff`, has the same key variable order and name as the first dataset array input to `join`, `ds3`.

See Also

[dataset](#) | [join](#) |

Related Examples

- “Add and Delete Variables” on page 2-104
- “Stack or Unstack Dataset Arrays” on page 2-127
- “Dataset Arrays in the Variables Editor” on page 2-143
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Stack or Unstack Dataset Arrays

This example shows how to reformat dataset arrays between wide and tall (or long) format using `stack` and `unstack`.

Load sample data.

Navigate to the folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the data from the comma-separated text file `testScores.csv`.

```
ds = dataset('File','testScores.csv','Delimiter',',',')
```

```
ds =
```

LastName	Sex	Test1	Test2	Test3	Test4
'HOWARD'	'male'	90	87	93	92
'WARD'	'male'	87	85	83	90
'TORRES'	'male'	86	85	88	86
'PETERSON'	'female'	75	80	72	77
'GRAY'	'female'	89	86	87	90
'RAMIREZ'	'female'	96	92	98	95
'JAMES'	'male'	78	75	77	77
'WATSON'	'female'	91	94	92	90
'BROOKS'	'female'	86	83	85	89
'KELLY'	'male'	79	76	82	80

Each of the 10 students has 4 test scores, displayed here in wide format.

With the data in this format, you can, for example, calculate the average test score for each student. The test scores are in columns 3 to 6.

```
ds.TestAve = mean(double(ds(:,3:6)),2);
ds(:,{'LastName','Sex','TestAve'})
```

```
ans =
```

LastName	Sex	TestAve
----------	-----	---------

'HOWARD'	'male'	90.5
'WARD'	'male'	86.25
'TORRES'	'male'	86.25
'PETERSON'	'female'	76
'GRAY'	'female'	88
'RAMIREZ'	'female'	95.25
'JAMES'	'male'	76.75
'WATSON'	'female'	91.75
'BROOKS'	'female'	85.75
'KELLY'	'male'	79.25

A new variable with average test scores is added to the dataset array, ds.

Reformat the dataset array into tall format.

Stack the test score variables into a new variable, Scores.

```
dsTall = stack(ds,{'Test1','Test2','Test3','Test4'},...
              'newDataVarName','Scores')
```

```
dsTall =
```

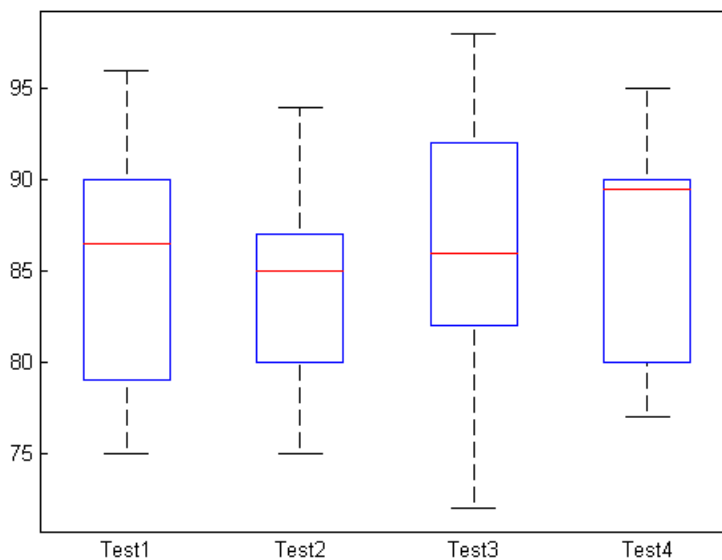
LastName	Sex	TestAve	Scores_Indicator	Scores
'HOWARD'	'male'	90.5	Test1	90
'HOWARD'	'male'	90.5	Test2	87
'HOWARD'	'male'	90.5	Test3	93
'HOWARD'	'male'	90.5	Test4	92
'WARD'	'male'	86.25	Test1	87
'WARD'	'male'	86.25	Test2	85
'WARD'	'male'	86.25	Test3	83
'WARD'	'male'	86.25	Test4	90
'TORRES'	'male'	86.25	Test1	86
'TORRES'	'male'	86.25	Test2	85
'TORRES'	'male'	86.25	Test3	88
'TORRES'	'male'	86.25	Test4	86
'PETERSON'	'female'	76	Test1	75
'PETERSON'	'female'	76	Test2	80
'PETERSON'	'female'	76	Test3	72
'PETERSON'	'female'	76	Test4	77
'GRAY'	'female'	88	Test1	89
'GRAY'	'female'	88	Test2	86

'GRAY'	'female'	88	Test3	87
'GRAY'	'female'	88	Test4	90
'RAMIREZ'	'female'	95.25	Test1	96
'RAMIREZ'	'female'	95.25	Test2	92
'RAMIREZ'	'female'	95.25	Test3	98
'RAMIREZ'	'female'	95.25	Test4	95
'JAMES'	'male'	76.75	Test1	78
'JAMES'	'male'	76.75	Test2	75
'JAMES'	'male'	76.75	Test3	77
'JAMES'	'male'	76.75	Test4	77
'WATSON'	'female'	91.75	Test1	91
'WATSON'	'female'	91.75	Test2	94
'WATSON'	'female'	91.75	Test3	92
'WATSON'	'female'	91.75	Test4	90
'BROOKS'	'female'	85.75	Test1	86
'BROOKS'	'female'	85.75	Test2	83
'BROOKS'	'female'	85.75	Test3	85
'BROOKS'	'female'	85.75	Test4	89
'KELLY'	'male'	79.25	Test1	79
'KELLY'	'male'	79.25	Test2	76
'KELLY'	'male'	79.25	Test3	82
'KELLY'	'male'	79.25	Test4	80

The original test variable names, `Test1`, `Test2`, `Test3`, and `Test4`, appear as levels in the combined test scores indicator variable, `Scores_Indicator`.

With the data in this format, you can use `Scores_Indicator` as a grouping variable, and draw box plots of test scores grouped by test.

```
figure()
boxplot(dsTall.Scores,dsTall.Scores_Indicator)
```



Reformat the dataset array into wide format.

Reformat `dsTall` back into its original wide format.

```
dsWide = unstack(dsTall, 'Scores', 'Scores_Indicator');  
dsWide(:, {'LastName', 'Test1', 'Test2', 'Test3', 'Test4'})
```

ans =

LastName	Test1	Test2	Test3	Test4
'HOWARD'	90	87	93	92
'WARD'	87	85	83	90
'TORRES'	86	85	88	86
'PETERSON'	75	80	72	77
'GRAY'	89	86	87	90
'RAMIREZ'	96	92	98	95
'JAMES'	78	75	77	77
'WATSON'	91	94	92	90

'BROOKS'	86	83	85	89
'KELLY'	79	76	82	80

The dataset array is back in wide format. `unstack` reassigns the levels of the indicator variable, `Scores_Indicator`, as variable names in the unstacked dataset array.

See Also

`dataset` | `double` | `stack` | `unstack` |

Related Examples

- “Access Data in Dataset Array Variables” on page 2-108
- “Calculations on Dataset Arrays” on page 2-132
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156
- “Grouping Variables” on page 2-72

Calculations on Dataset Arrays

This example shows how to perform calculations on dataset arrays.

Load sample data.

Navigate to the folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the data from the comma-separated text file `testScores.csv`.

```
ds = dataset('File','testScores.csv','Delimiter','(',')')
```

```
ds =
```

LastName	Sex	Test1	Test2	Test3	Test4
'HOWARD'	'male'	90	87	93	92
'WARD'	'male'	87	85	83	90
'TORRES'	'male'	86	85	88	86
'PETERSON'	'female'	75	80	72	77
'GRAY'	'female'	89	86	87	90
'RAMIREZ'	'female'	96	92	98	95
'JAMES'	'male'	78	75	77	77
'WATSON'	'female'	91	94	92	90
'BROOKS'	'female'	86	83	85	89
'KELLY'	'male'	79	76	82	80

There are 4 test scores for each of 10 students, in wide format.

Average dataset array variables.

Compute the average (mean) test score for each student in the dataset array, and store it in a new variable, `TestAvg`. Test scores are in columns 3 to 6.

Use `double` to convert the specified dataset array variables into a numeric array. Then, calculate the mean across the second dimension (across columns) to get the test average for each student.

```
ds.TestAvg = mean(double(ds(:,3:6)),2);
```

```
ds(:, {'LastName', 'TestAvg'})
```

```
ans =
```

LastName	TestAvg
'HOWARD'	90.5
'WARD'	86.25
'TORRES'	86.25
'PETERSON'	76
'GRAY'	88
'RAMIREZ'	95.25
'JAMES'	76.75
'WATSON'	91.75
'BROOKS'	85.75
'KELLY'	79.25

Summarize the dataset array using a grouping variable.

Compute the mean and maximum average test scores for each gender.

```
stats = grpstats(ds, 'Sex', {'mean', 'max'}, 'DataVars', 'TestAvg')
```

```
stats =
```

	Sex	GroupCount	mean_TestAvg	max_TestAvg
male	'male'	5	83.8	90.5
female	'female'	5	87.35	95.25

This returns a new dataset array containing the specified summary statistics for each level of the grouping variable, Sex.

Replace data values.

The denominator for each test score is 100. Convert the test score denominator to 25.

```
scores = double(ds(:,3:6));
newScores = scores*25/100;
ds = replacedata(ds,newScores,3:6)
```

```
ds =
```

LastName	Sex	Test1	Test2	Test3	Test4	T
'HOWARD'	'male'	22.5	21.75	23.25	23	
'WARD'	'male'	21.75	21.25	20.75	22.5	8
'TORRES'	'male'	21.5	21.25	22	21.5	8
'PETERSON'	'female'	18.75	20	18	19.25	
'GRAY'	'female'	22.25	21.5	21.75	22.5	
'RAMIREZ'	'female'	24	23	24.5	23.75	9
'JAMES'	'male'	19.5	18.75	19.25	19.25	7
'WATSON'	'female'	22.75	23.5	23	22.5	9
'BROOKS'	'female'	21.5	20.75	21.25	22.25	8
'KELLY'	'male'	19.75	19	20.5	20	7

The first two lines of code extract the test data and perform the desired calculation. Then, `replacedata` inserts the new test scores back into the dataset array.

The variable of test score averages, `TestAvg`, is now the final score for each student. Change the variable name to `Final`.

```
ds.Properties.VarNames{end} = 'Final';
ds
```

```
ds =
```

LastName	Sex	Test1	Test2	Test3	Test4	F
'HOWARD'	'male'	22.5	21.75	23.25	23	
'WARD'	'male'	21.75	21.25	20.75	22.5	8
'TORRES'	'male'	21.5	21.25	22	21.5	8
'PETERSON'	'female'	18.75	20	18	19.25	
'GRAY'	'female'	22.25	21.5	21.75	22.5	
'RAMIREZ'	'female'	24	23	24.5	23.75	9
'JAMES'	'male'	19.5	18.75	19.25	19.25	7
'WATSON'	'female'	22.75	23.5	23	22.5	9
'BROOKS'	'female'	21.5	20.75	21.25	22.25	8
'KELLY'	'male'	19.75	19	20.5	20	7

See Also

`dataset` | `double` | `replacedata` | `grpstats`

**Related
Examples**

- “Stack or Unstack Dataset Arrays” on page 2-127
- “Access Data in Dataset Array Variables” on page 2-108
- “Select Subsets of Observations” on page 2-114
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Export Dataset Arrays

This example shows how to export a dataset array from the MATLAB workspace to a text or spreadsheet file.

Load sample data.

```
load('hospital')
```

The dataset array has 100 observations and 7 variables.

Export to a text file.

Export the dataset array, `hospital`, to a text file named `hospital.txt`. By default, `export` writes to a tab-delimited text file with the same name as the dataset array, appended by `.txt`.

```
export(hospital)
```

This creates the file `hospital.txt` in the current working folder, if it does not previously exist. If the file already exists in the current working folder, `export` overwrites the existing file.

By default, variable names are in the first line of the text file. Observation names, if present, are in the first column.

Now, `export hospital` with variable names suppressed to a text file named `NoLabels.txt`.

```
export(hospital,'File','NoLabels.txt','WriteVarNames',false)
```

There are no variable names in the first line of the created text file, `NoLabels.txt`.

Export to a comma-delimited format.

Export `hospital` to a comma-delimited text file, `hospital.csv`.

```
export(hospital,'File','hospital.csv','Delimiter',',',')
```

Export to an Excel spreadsheet.

Export `hospital` to an Excel spreadsheet named `hospital.xlsx`.

```
export(hospital, 'XLSFile', 'hospital.xlsx')
```

By default, the first row of `hospital.xlsx` has variable names, and the first column has observation names.

See Also

[dataset](#) | [export](#) |

Related Examples

- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Create a Dataset Array from a File” on page 2-92

Concepts

- “Dataset Arrays” on page 2-156

Clean Messy and Missing Data

This example shows how to find, clean, and delete observations with missing data in a dataset array.

Load sample data.

Navigate to the folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Import the data from the spreadsheet `messy.xlsx`.

```
messyData = dataset('XLSFile','messy.xlsx')
```

```
messyData =
```

var1	var2	var3	var4	var5
'afe1'	'3'	'yes'	'3'	3
'egh3'	'.'	'no'	'7'	7
'wth4'	'3'	'yes'	'3'	3
'atn2'	'23'	'no'	'23'	23
'arg1'	'5'	'yes'	'5'	5
'jre3'	'34.6'	'yes'	'34.6'	34.6
'wen9'	'234'	'yes'	'234'	234
'ple2'	'2'	'no'	'2'	2
'dbo8'	'5'	'no'	'5'	5
'oii4'	'5'	'yes'	'5'	5
'wnk3'	'245'	'yes'	'245'	245
'abk6'	'563'	''	'563'	563
'pnj5'	'463'	'no'	'463'	463
'wnn3'	'6'	'no'	'6'	6
'oks9'	'23'	'yes'	'23'	23
'wba3'	''	'yes'	'NaN'	14
'pkn4'	'2'	'no'	'2'	2
'adw3'	'22'	'no'	'22'	22
'poj2'	'-99'	'yes'	'-99'	-99
'bas8'	'23'	'no'	'23'	23
'gry5'	'NA'	'yes'	'NaN'	21

When you import data from a spreadsheet, `dataset` reads any variables with nonnumeric elements as a cell array of strings. This is why the variable `var2` is a cell array of strings. When importing data from a text file, you have more flexibility to specify which nonnumeric expressions to treat as missing using the option `TreatAsEmpty`.

There are many different missing data indicators in `messy.xlsx`, such as:

- Empty cells
- A period (.)
- NA
- NaN
- -99

Find observations with missing values.

Display the subset of observations that have at least one missing value using `ismissing`.

```
ix = ismissing(messyData, 'NumericTreatAsMissing', -99, ...
              'StringTreatAsMissing', {'NaN', '.', 'NA'});
messyData(any(ix,2),:)
```

ans =

var1	var2	var3	var4	var5
'egh3'	'.'	'no'	'7'	7
'abk6'	'563'	''	'563'	563
'wba3'	''	'yes'	'NaN'	14
'poj2'	'-99'	'yes'	'-99'	-99
'gry5'	'NA'	'yes'	'NaN'	21

By default, `ismissing` recognizes the following missing value indicators:

- NaN for numeric arrays
- '' for string arrays
- <undefined> for categorical arrays

Use the `NumericTreatAsMissing` and `StringTreatAsMissing` options to specify other values to treat as missing.

Convert string arrays to double arrays.

You can convert the string variables that should be numeric using `str2double`.

```
messyData.var2 = str2double(messyData.var2);  
messyData.var4 = str2double(messyData.var4);
```

```
messyData =
```

var1	var2	var3	var4	var5
'afe1'	3	'yes'	3	3
'egh3'	NaN	'no'	7	7
'wth4'	3	'yes'	3	3
'atn2'	23	'no'	23	23
'arg1'	5	'yes'	5	5
'jre3'	34.6	'yes'	34.6	34.6
'wen9'	234	'yes'	234	234
'ple2'	2	'no'	2	2
'dbo8'	5	'no'	5	5
'oii4'	5	'yes'	5	5
'wnk3'	245	'yes'	245	245
'abk6'	563	' '	563	563
'pnj5'	463	'no'	463	463
'wnn3'	6	'no'	6	6
'oks9'	23	'yes'	23	23
'wba3'	NaN	'yes'	NaN	14
'pkn4'	2	'no'	2	2
'adw3'	22	'no'	22	22
'poj2'	-99	'yes'	-99	-99
'bas8'	23	'no'	23	23
'gry5'	NaN	'yes'	NaN	21

Now, `var2` and `var4` are numeric arrays. During the conversion, `str2double` replaces the nonnumeric elements of the variables `var2` and `var4` with the value `NaN`. However, there are no changes to the numeric missing value indicator, `-99`.

When applying the same function to many dataset array variables, it can sometimes be more convenient to use `datasetfun`. For example, to convert both `var2` and `var4` to numeric arrays simultaneously, you can use:

```
messyData(:,[2,4]) = datasetfun(@str2double,messyData,'DataVars',[2,4],...
                               'DatasetOutput',true);
```

Replace missing value indicators.

Clean the data so that the missing values indicated by the code `-99` have the standard MATLAB numeric missing value indicator, `NaN`.

```
messyData = replaceWithMissing(messyData,'NumericValues',-99)
```

```
messyData =
```

var1	var2	var3	var4	var5
'afe1'	3	'yes'	3	3
'egh3'	NaN	'no'	7	7
'wth4'	3	'yes'	3	3
'atn2'	23	'no'	23	23
'arg1'	5	'yes'	5	5
'jre3'	34.6	'yes'	34.6	34.6
'wen9'	234	'yes'	234	234
'ple2'	2	'no'	2	2
'dbo8'	5	'no'	5	5
'oii4'	5	'yes'	5	5
'wnk3'	245	'yes'	245	245
'abk6'	563	' '	563	563
'pnj5'	463	'no'	463	463
'wnn3'	6	'no'	6	6
'oks9'	23	'yes'	23	23
'wba3'	NaN	'yes'	NaN	14
'pkn4'	2	'no'	2	2
'adw3'	22	'no'	22	22
'poj2'	NaN	'yes'	NaN	NaN
'bas8'	23	'no'	23	23
'gry5'	NaN	'yes'	NaN	21

Create a dataset array with complete observations.

Create a new dataset array that contains only the complete observations—those without missing data.

```
ix = ismissing(messyData);  
completeData = messyData(~any(ix,2),:)
```

```
completeData =
```

var1	var2	var3	var4	var5
'afe1'	3	'yes'	3	3
'wth4'	3	'yes'	3	3
'atn2'	23	'no'	23	23
'arg1'	5	'yes'	5	5
'jre3'	34.6	'yes'	34.6	34.6
'wen9'	234	'yes'	234	234
'ple2'	2	'no'	2	2
'dbo8'	5	'no'	5	5
'oii4'	5	'yes'	5	5
'wnk3'	245	'yes'	245	245
'pnj5'	463	'no'	463	463
'wnn3'	6	'no'	6	6
'oks9'	23	'yes'	23	23
'pkn4'	2	'no'	2	2
'adw3'	22	'no'	22	22
'bas8'	23	'no'	23	23

See Also

[dataset](#) | [ismissing](#) | [replaceWithMissing](#) |

Related Examples

- “Select Subsets of Observations” on page 2-114
- “Calculations on Dataset Arrays” on page 2-132
- “Index and Search Dataset Arrays” on page 2-159

Concepts

- “Dataset Arrays” on page 2-156

Dataset Arrays in the Variables Editor

In this section...

“Open Dataset Arrays in the Variables Editor” on page 2-143

“Modify Variable and Observation Names” on page 2-144

“Reorder or Delete Variables” on page 2-146

“Add New Data” on page 2-148

“Sort Observations” on page 2-150

“Select a Subset of Data” on page 2-151

“Create Plots” on page 2-154

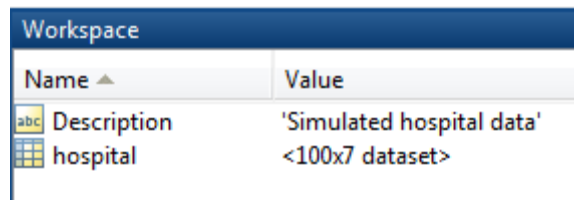
Open Dataset Arrays in the Variables Editor

The MATLAB Variables editor provides a convenient interface for viewing, modifying, and plotting dataset arrays.

First, load the sample data set, `hospital`.

```
load('hospital')
```

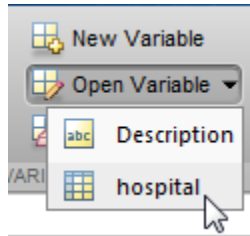
The dataset array, `hospital`, is created in the MATLAB workspace.



Workspace	
Name ▲	Value
abc Description	'Simulated hospital data'
hospital	<100x7 dataset>

The dataset array has 100 observations and 7 variables.

To open `hospital` in the Variables editor, click **Open Variable**, and select `hospital`.



The Variables editor opens, displaying the contents of the dataset array (only the first 10 observations are shown here).

hospital <100x7 dataset>							
	1	2	3	4	5	6	
	LastName	Sex	Age	Weight	Smoker	BloodPressure	
1	YPL-320	'SMITH'	Male	38	176	1	124 93 18
2	GLI-532	'JOHNSON'	Male	43	163	0	109 77 [11,
3	PNI-258	'WILLIAMS'	Female	38	131	0	125 83 []
4	MIJ-579	'JONES'	Female	40	133	0	117 75 [6,1,
5	XLK-030	'BROWN'	Female	49	119	0	122 80 [14,
6	TFP-518	'DAVIS'	Female	46	142	0	121 70 19
7	LPD-746	'MILLER'	Female	33	142	1	130 88 13
8	ATA-945	'WILSON'	Male	40	180	0	115 82 []
9	VNL-702	'MOORE'	Male	28	183	0	115 78 2
10	LQW-768	'TAYLOR'	Female	31	132	0	118 86 11

In the Variables editor, you can see the names of the seven variables along the top row, and the observations names down the first column.

Modify Variable and Observation Names

You can modify variable and observation names by double-clicking a name, and then typing new text.

hospital <100x7 dataset>		
	1	2
	LastName	Sex
1 YPL-320	'SMITH'	Male
2 GLI-532	'JOHNSON'	Male
3 PNI-258	'WILLIAMS'	Female

hospital <100x7 dataset>		
	1	2
	LastName	Gender
1 YPL-320	'SMITH'	Male
2 GLI-532	'JOHNSON'	Male
3 PNI-258	'WILLIAMS'	Female
4 MIJ-579	'JONES'	Female
5 XLK-030	'BROWN'	Female

All changes made in the Variables editor are also sent to the command line.

```
Command Window
>> hospital.Properties.VarNames{2} = 'Gender';
fx >>
```

The sixth variable in the data set, `BloodPressure`, is a numeric array with two columns. The first column shows systolic blood pressure, and the second column shows diastolic blood pressure. Click the arrow that appears on the right side of the variable name cell to see the units and description of the variable. You can type directly in the units and description fields to modify the text. The variable data type and size are shown under the variable description.

6	7	8	9
BloodPressure	Trials		
124	Ascending		
109	Descending		
125	UNITS		
117	mm Hg		
122	DESCRIPTION		
121	Systolic/Diastolic		
130			
115			
115			

Reorder or Delete Variables

You can reorder variables in a dataset array using the Variables editor. Hover over the left side of a variable name cell until a four-headed arrow appears.

4	5
Weight	Smoker
176	1
163	0
131	0
133	0
119	0
142	0

After the arrow appears, click and drag the variable column to a new location.

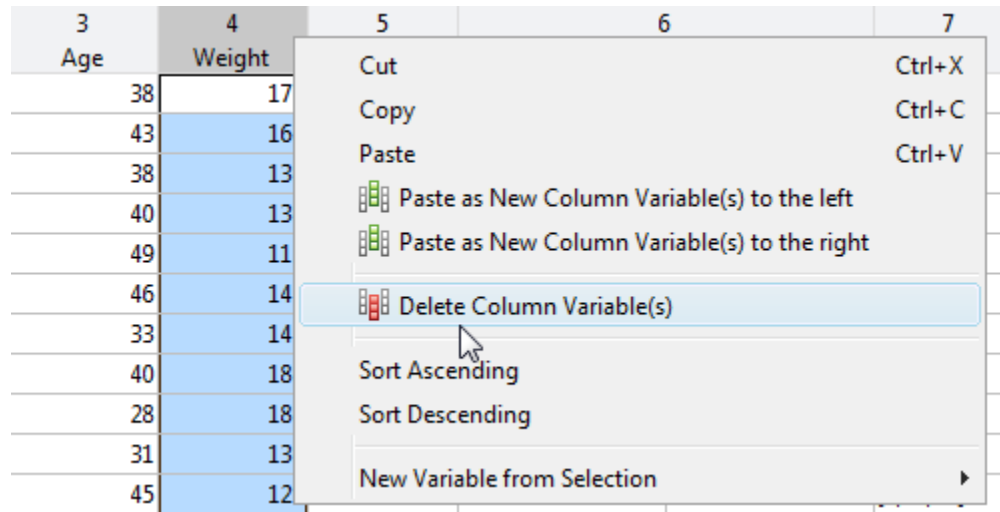
4	5	5	6
Weight	Smoke	Smoker	BloodPressure
176	1	1	124
163	0	0	109
131	0	0	125
133	0	0	117
119	0	0	122
142	0	0	121
142	1	1	130
180	0	0	115
183	0	0	115
132	0	0	118
128	0	0	114
137	0	0	115
174	0	0	127

5	6	7
BloodPressure	Smoker	Trials
124	93	1 18
109	77	0 [11,13,22]
125	83	0 []
117	75	0 [6,12]
122	80	0 [14,23]
121	70	0 19
130	88	1 17

The command for the variable reordering appears in the command line.

```
Command Window
>> hospital = hospital(:, [1:4 6 5 end]);
fx >>
```

You can delete a variable in the Variables editor by selecting the variable column, right-clicking, and selecting **Delete Column Variable(s)**.



The command for the variable deletion appears in the command line.

```
Command Window
>> hospital(:, 'Weight') = [];
fx >>
```

Add New Data

You can enter new data values directly into the Variables editor. For example, you can add a new patient observation to the `hospital` data set. To enter a new last name, add a string to the end of the variable `LastName`.

100	ZZB-405	'HAYES'	Male	48	114	86
101		'JONES'				
102						

The variable `Gender` is a nominal array. The levels of the categorical variable appear in a drop-down list when you double-click a cell in the `Gender` column.

You can choose one of the levels previously used, or create a new level by selecting **New Item**.

100	ZZB-405	'HAYES'	Male
101	Obs101	'JONES'	Female
102			Female
103			Male
104			New item
105			

You can continue to add data for the remaining variables.

To change the observation name, click the observation name and type the new name.

100	ZZB-405	'HAYES'	Male	48
101	Obs101	'JONES'	Female	45
102				

The commands for entering the new data appear at the command line.

```

Command Window
>> hospital.LastName{101} = 'JONES';
Warning: Observations with default values added to dataset
variables.
> In dataset.subsasgn at 584
>> hospital.Sex(101) = 'Female';
>> hospital.Age(101) = 45;
>> hospital.BloodPressure(101,2) = 85;
>> hospital.BloodPressure(101,1) = 120;
>> hospital.Properties.ObsNames{101} = 'QPO-187';
fx >>

```

Notice the warning that appears after the first assignment. When you enter the first piece of data in the new observation row—here, the last name—default values are assigned to all other variables. Default assignments are:

- 0 for numeric variables
- <undefined> for categorical variables
- [] for cell arrays

You can also copy and paste data from one dataset array to another using the Variables editor.

Sort Observations

You can use the Variables editor to sort dataset array observations by the values of one or more variables. To sort by gender, for example, select the variable Gender. Then click **Sort**, and choose to sort rows by ascending or descending values of the selected variable.

	1	2	3	4	5	6		
	LastName	Gender	Age	BloodPressure	Smoker	Trials		
1	YPL-320	'SMITH'	Male	38	124	93	1	18
2	GLI-532	'JOHNSON'	Male	43	109	77	0	[11,13,22]
3	PNI-258	'WILLIAMS'	Female	38	125	83	0	[]
4	MJ-579	'JONES'	Female	40	117	75	0	[6,12]
5	XLK-030	'BROWN'	Female	49	122	80	0	[14,23]

When sorting by variables that are cell arrays of strings or of nominal data type, observations are sorted alphabetically. For ordinal variables, rows are sorted by the ordering of the levels. For example, when the observations of `hospital` are sorted by the values in `Gender`, the females are grouped together, followed by the males.

hospital <100x6 dataset>			
	1 LastName	2 Gender	3 Age
1 PNI-258	'WILLIAMS'	Female	38
2 MU-579	'JONES'	Female	40
3 XLK-030	'BROWN'	Female	49
4 TFP-518	'DAVIS'	Female	46
5 LPD-746	'MILLER'	Female	33
6 LQW-768	'TAYLOR'	Female	31
7 QFY-472	'ANDERSON'	Female	45
8 UJG-627	'THOMAS'	Female	42
9 ELG-976	'HARRIS'	Female	36
10 XBR-291	'GARCIA'	Female	27

To sort by the values of multiple variables, press **Ctrl** while you select multiple variables.

When you use the Variables editor to sort rows, it is the same as calling `sortrows`. You can see this at the command line after executing the sorting.

```
Command Window
>> hospital = sortrows(hospital, 'Gender', 'ascend');
fx >>
```

Select a Subset of Data

You can select a subset of data from a dataset array in the Variables editor, and create a new dataset array from the selection. For example, to create a dataset array containing only the variables `LastName` and `Age`:

- 1 Hold **Ctrl** while you click the variables `LastName` and `Age`.
- 2 Right-click, and select **New Variable from Selection > New Dataset Array**.

hospital <100x6 dataset>

	1	2	3	4	5	6
	LastName	Gender	Age	BloodPressure	Smoker	Trials
1	PNI-258	'WILLIAMS'	Female			
2	MIJ-579	'JONES'	Female			
3	XLK-030	'BROWN'	Female			
4	TFP-518	'DAVIS'	Female			
5	LPD-746	'MILLER'	Female			
6	LQW-768	'TAYLOR'	Female			
7	QFY-472	'ANDERSON'	Female			
8	UJG-627	'THOMAS'	Female			
9	ELG-976	'HARRIS'	Female			
10	XBR-291	'GARCIA'	Female			
11	BKD-785	'CLARK'	Female			
12	JHV-416	'RODRIGUEZ'	Female			
13	VWL-936	'LEWIS'	Female	41	114	88
14	AAX-056	'LEE'	Female	44	128	90
15	DTT-578	'WALKER'	Female	28	129	96

Context menu options: Cut (Ctrl+X), Copy (Ctrl+C), Paste (Ctrl+V), Paste as New Column Variable(s) to the left, Paste as New Column Variable(s) to the right, Delete Column Variable(s), Sort Ascending, Sort Descending, New Variable from Selection.

The new dataset array appears in the Workspace window with the name `LastName`. The Command Window shows the commands that execute the selection.

Workspace

Name	Value
Description	'Simulated hospital data'
LastName	<100x2 dataset>
hospital	<100x6 dataset>

Command Window

```
>> LastName = hospital(:, [1,3]);
fx >>
```

You can use the same steps to select any subset of data. To select observations according to some logical condition, you can use a combination of sorting and selecting. For example, to create a new dataset array containing only males aged 45 and older:

- 1 Sort the observations of `hospital` by the values in `Gender` and `Age`, descending.
- 2 Select the male observations with age 45 and older.

hospital <100x6 dataset>

	1 LastName	2 Gender	3 Age	4 BloodPressure	5 Smoker	6 Trials
1 XBA-581	'ROBINSON'	Male	50	125	76	0 [20,26,30]
2 DAU-529	'REED'	Male	50	129	89	1 22
3 FLJ-908	'STEWART'	Male	49	129	95	1 15
4 MEZ-469	'GRIFFIN'	Male	49	119	74	0 9
5 KOQ-996	'MARTIN'	Male	48	130	92	1 [13,15,21,27]
6 FCD-425	'GONZALES'	Male	48	123	79	0 []
7 ZZB-405	'HAYES'	Male	48	114	86	0 28
8 YVY-570	'SCOTT'	Male	47	127	84	0 8
9 VDZ-577	'PHILLIPS'	Male	45	117	89	0 [10,15,17,19]
10 WCJ-997	'BELL'	Male	45	138	82	1 7
11 AGR-528	'SIMMONS'	Male	45	124	77	0 [8,18,25]
12 BEZ-311	'DIAZ'	Male	45	136	93	1 []
13 MSL-692	'GREEN'	Male	44	121	92	0 []

- 3** Right-click, and select **New Variables from Selection > New Dataset Array**. The new dataset array, LastName1, is created in the Workspace window.

Workspace

Name	Value
Description	'Simulated hospital data'
LastName	<100x2 dataset>
LastName1	<12x6 dataset>
hospital	<100x6 dataset>

Command Window

```
>> hospital = sortrows(hospital, {'Gender',
>> LastName1 = hospital(1:12,1:6);
fx >>
```

- 4** You can rename the dataset array in the Workspace window.

Workspace

Name	Value
Description	'Simulated hospital data'
LastName	<100x2 dataset>
Male45	<12x6 dataset>
hospital	<100x6 dataset>

Create Plots

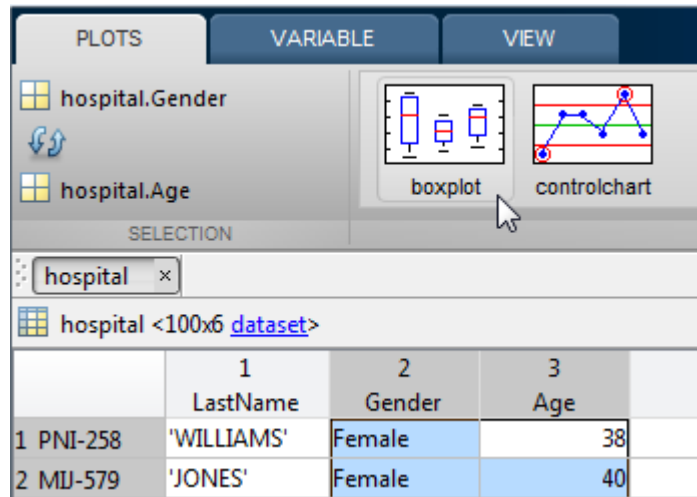
You can plot data from a dataset array using plotting options in the Variables editor. Available plot choices depend on the data types of variables to be plotted.

For example, if you select the variable **Age**, you can see in the **Plots** tab some plotting options that are appropriate for a univariate, numeric variable.

The screenshot shows a software interface with a 'PLOTS' tab selected. Underneath, the variable 'hospital.Age' is listed. To the right, five plot options are displayed: 'plot' (line graph), 'bar' (bar chart), 'area' (area chart), 'pie' (pie chart), and 'hist' (histogram). Below the plot options is a 'SELECTION' dropdown menu showing 'hospital'. Underneath that is a data preview table for the 'hospital' dataset.

	1	2	3	4		
	LastName	Gender	Age	BloodPressure	Sm	
1	PNI-258	'WILLIAMS'	Female	38	125	83
2	MJ-579	'JONES'	Female	40	117	75
3	XLK-030	'BROWN'	Female	49	122	80
4	TFP-518	'DAVIS'	Female	46	121	70
5	LPD-746	'MILLER'	Female	33	130	88

Sometimes, there are plot options for multiple variables, depending on their data types. For example, if you select both **Age** and **Gender**, you can draw box plots of age, grouped by gender.



The screenshot shows the 'PLOTS' tab in the Variables Editor. The 'hospital' dataset is selected, and the 'hospital.Age' variable is highlighted. The 'boxplot' and 'controlchart' options are visible in the plot selection area. Below the plot area, a data table is displayed with columns for observation number, LastName, Gender, and Age.

	1	2	3	
	LastName	Gender	Age	
1	PNI-258	'WILLIAMS'	Female	38
2	MIJ-579	'JONES'	Female	40

See Also

dataset | sortrows |

Related Examples

- “Add and Delete Observations” on page 2-100
- “Add and Delete Variables” on page 2-104
- “Access Data in Dataset Array Variables” on page 2-108
- “Select Subsets of Observations” on page 2-114
- “Sort Observations in Dataset Arrays” on page 2-118

Concepts

- “Dataset Arrays” on page 2-156

Dataset Arrays

In this section...

“What Are Dataset Arrays?” on page 2-156

“Dataset Array Conversion” on page 2-156

“Dataset Array Properties” on page 2-157

What Are Dataset Arrays?

Statistics Toolbox has *dataset arrays* for storing variables with heterogeneous data types. For example, you can combine numeric data, logical data, cell arrays of strings, and categorical arrays in one dataset array variable.

Within a dataset array, each variable (column) must be one homogeneous data type, but the different variables can be of heterogeneous data types. A dataset array is usually interpreted as a set of variables measured on many units of observation. That is, each row in a dataset array corresponds to an observation, and each column to a variable. In this sense, a dataset array organizes data like a typical spreadsheet.

Dataset arrays are a unique data type, with a corresponding set of valid operations. Even if a dataset array contains only numeric variables, you cannot operate on the dataset array like a numeric variable. The valid operations for dataset arrays are the methods of the `dataset` class.

Dataset Array Conversion

You can create a dataset array by combining variables that exist in the MATLAB workspace, or directly importing data from a file, such as a text file or spreadsheet. This table summarizes the functions you can use to create dataset arrays.

Data Source	Conversion to Dataset Array
Data from a file	<code>dataset</code>
Heterogeneous collection of workspace variables	<code>dataset</code>

Data Source	Conversion to Dataset Array
Numeric array	<code>mat2dataset</code>
Cell array	<code>cell2dataset</code>
Structure array	<code>struct2dataset</code>

You can export dataset arrays to text or spreadsheet files using `export`. To convert a dataset array to a cell array or structure array, use `dataset2cell` or `dataset2struct`.

Dataset Array Properties

In addition to storing data in a dataset array, you can store metadata such as:

- Variable and observation names
- Data descriptions
- Units of measurement
- Variable descriptions

This information is stored as dataset array properties. For a dataset array named `ds`, you can view the dataset array metadata by entering `ds.Properties` at the command line. You can access a specific property, such as variable names—property `VarNames`—using `ds.Properties.VarNames`. You can both retrieve and modify property values using this syntax.

Variable and observation names are included in the display of a dataset array. Variable names display across the top row, and observation names, if present, appear in the first column. Note that variable and observation names do not affect the size of a dataset array.

See Also

`dataset` | `export` | `dataset2cell` | `dataset2struct` | `mat2dataset` | `cell2dataset` | `struct2dataset`

Related Examples

- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Create a Dataset Array from a File” on page 2-92
- “Export Dataset Arrays” on page 2-136
- “Dataset Arrays in the Variables Editor” on page 2-143

- “Index and Search Dataset Arrays” on page 2-159

Index and Search Dataset Arrays

There are many ways to index into dataset arrays. For example, for a dataset array, `ds`, you can:

- Use `()` to create a new dataset array from a subset of `ds`. For example, `ds1 = ds(1:5, :)` creates a new dataset array, `ds1`, consisting of the first five rows of `ds`. Metadata, including variable and observation names, transfers to the new dataset array.
- Use variable names with dot notation to index individual variables in a dataset array. For example, `ds.Height` indexes the variable named `Height`.
- Use observation names to index individual observations in a dataset array. For example, `ds('Obs1', :)` gives data for the observation named `Obs1`.
- Use observation or variable numbers. For example, `ds(:, [1,3,5])` gives the data in the first, third, and fifth variables (columns) of `ds`.
- Use logical indexing to search for observations in `ds` that satisfy a logical condition. For example, `ds(ds.Gender=='Male', :)` gives the observations in `ds` where the variable named `Gender`, a nominal array, has the value `Male`.
- Use `ismissing` to find missing data in the dataset array.

The following brief examples illustrate several indexing and searching methods.

Load sample data.

```
load('hospital')
size(hospital)
```

```
ans =
    100     7
```

The dataset array has 100 observations and 7 variables.

Index the variable by name.

Return the minimum age in the dataset array.

```
min(hospital.Age)
```

```
ans =
```

```
25
```

Delete the variable Trials.

```
hospital.Trials = [];  
size(hospital)
```

```
ans =
```

```
100    6
```

Index the observation by name.

Display measurements on the first five variables for the observation named PUE-347.

```
hospital('PUE-347',1:5)
```

```
ans =
```

	LastName	Sex	Age	Weight	Smoker
PUE-347	'YOUNG'	Female	25	114	false

Index variables by number.

Create a new dataset array containing the first four variables of hospital.

```
dsNew = hospital(:,1:4);  
dsNew.Properties.VarNames(:)
```

```
ans =
```

```
'LastName'  
'Sex'  
'Age'  
'Weight'
```

Index observations by number.

Delete the last 10 observations.

```
hospital(end-9:end,:) = [];
size(hospital)
```

```
ans =
```

```
    90     7
```

Search for observations by logical condition.

Create a new dataset array containing only females who smoke.

```
dsFS = hospital(hospital.Sex=='Female' & hospital.Smoker==true,:);
dsFS(:, {'LastName', 'Sex', 'Smoker'})
```

```
ans =
```

	LastName	Sex	Smoker
LPD-746	'MILLER'	Female	true
XBR-291	'GARCIA'	Female	true
AAX-056	'LEE'	Female	true
DTT-578	'WALKER'	Female	true
AFK-336	'WRIGHT'	Female	true
RBA-579	'SANCHEZ'	Female	true
HAK-381	'MORRIS'	Female	true
NSK-403	'RAMIREZ'	Female	true
ILS-109	'WATSON'	Female	true
JDR-456	'SANDERS'	Female	true
HWZ-321	'PATTERSON'	Female	true
GGU-691	'HUGHES'	Female	true
WUS-105	'FLORES'	Female	true

See Also [dataset](#) |

Related Examples

- “Access Data in Dataset Array Variables” on page 2-108
- “Select Subsets of Observations” on page 2-114

Concepts

- “Dataset Arrays” on page 2-156

Descriptive Statistics

- “Introduction to Descriptive Statistics” on page 3-2
- “Measures of Central Tendency” on page 3-3
- “Measures of Dispersion” on page 3-5
- “Quantiles and Percentiles” on page 3-7
- “Exploratory Analysis of Data” on page 3-11
- “Resampling Statistics” on page 3-16
- “Data with Missing Values” on page 3-21

Introduction to Descriptive Statistics

You may need to summarize large, complex data sets—both numerically and visually—to convey their essence to the data analyst and to allow for further processing.

Measures of Central Tendency

Measures of central tendency locate a distribution of data along an appropriate scale.

The following table lists the functions that calculate the measures of central tendency.

Function Name	Description
geomean	Geometric mean
harmmean	Harmonic mean
mean	Arithmetic average
median	50th percentile
mode	Most frequent value
trimmean	Trimmed mean

The average is a simple and popular estimate of location. If the data sample comes from a normal distribution, then the sample mean is also optimal (minimum variance unbiased estimator (MVUE) of μ).

Unfortunately, outliers, data entry errors, or glitches exist in almost all real data. The sample mean is sensitive to these problems. One bad data value can move the average away from the center of the rest of the data by an arbitrarily large distance.

The median and trimmed mean are two measures that are resistant (robust) to outliers. The median is the 50th percentile of the sample, which will only change slightly if you add a large perturbation to any value. The idea behind the trimmed mean is to ignore a small percentage of the highest and lowest values of a sample when determining the center of the sample.

The geometric mean and harmonic mean, like the average, are not robust to outliers. They are useful when the sample is distributed lognormal or heavily skewed.

The following example shows the behavior of the measures of location for a sample with one outlier.

```
x = [ones(1,6) 100]
```

```
x =  
    1    1    1    1    1    1   100
```

```
locate = [geomean(x) harmmean(x) mean(x) median(x)...  
          trimmean(x,25)]
```

```
locate =  
    1.9307    1.1647    15.1429    1.0000    1.0000
```

You can see that the mean is far from any data value because of the influence of the outlier. The median and trimmed mean ignore the outlying value and describe the location of the rest of the data values.

Measures of Dispersion

The purpose of measures of dispersion is to find out how spread out the data values are on the number line. Another term for these statistics is measures of spread.

The table gives the function names and descriptions.

Function Name	Description
iqr	Interquartile range
mad	Mean absolute deviation
moment	Central moment of all orders
range	Range
std	Standard deviation
var	Variance

The range (the difference between the maximum and minimum values) is the simplest measure of spread. But if there is an outlier in the data, it will be the minimum or maximum value. Thus, the range is not robust to outliers.

The standard deviation and the variance are popular measures of spread that are optimal for normally distributed samples. The sample variance is the minimum variance unbiased estimator (MVUE) of the normal parameter σ^2 . The standard deviation is the square root of the variance and has the desirable property of being in the same units as the data. That is, if the data is in meters, the standard deviation is in meters as well. The variance is in meters², which is more difficult to interpret.

Neither the standard deviation nor the variance is robust to outliers. A data value that is separate from the body of the data can increase the value of the statistics by an arbitrarily large amount.

The mean absolute deviation (MAD) is also sensitive to outliers. But the MAD does not move quite as much as the standard deviation or variance in response to bad data.

The interquartile range (IQR) is the difference between the 75th and 25th percentile of the data. Since only the middle 50% of the data affects this measure, it is robust to outliers.

The following example shows the behavior of the measures of dispersion for a sample with one outlier.

```
x = [ones(1,6) 100]

x =
     1     1     1     1     1     1    100

stats = [iqr(x) mad(x) range(x) std(x)]

stats =
     0    24.2449    99.0000    37.4185
```


Quantiles and Percentiles

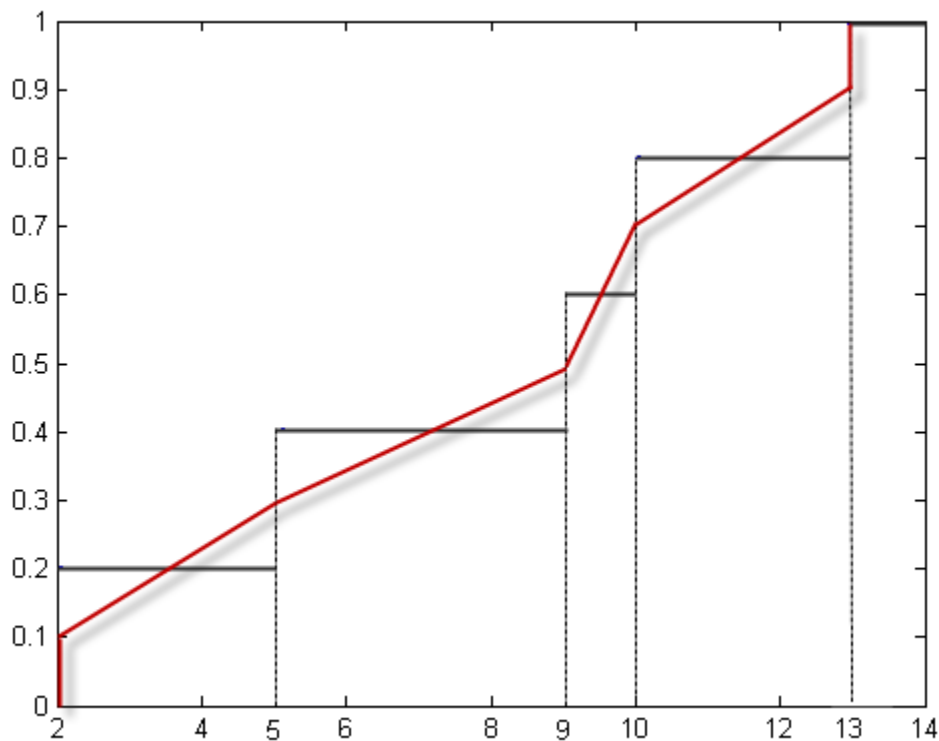
This section explains how the Statistics Toolbox functions `quantile` and `prctile` compute quantiles and percentiles.

The `prctile` function calculates the percentiles in a similar way as `quantile` calculates quantiles. The following steps in the computation of quantiles are also true for percentiles, given the fact that, for the same data sample, the quantile at the value Q is the same as the percentile at the value $P = 100 * Q$.

1 `quantile` initially assigns the sorted values in X to the $(0.5/n)$, $(1.5/n)$, ..., $([n - 0.5]/n)$ quantiles. For example:

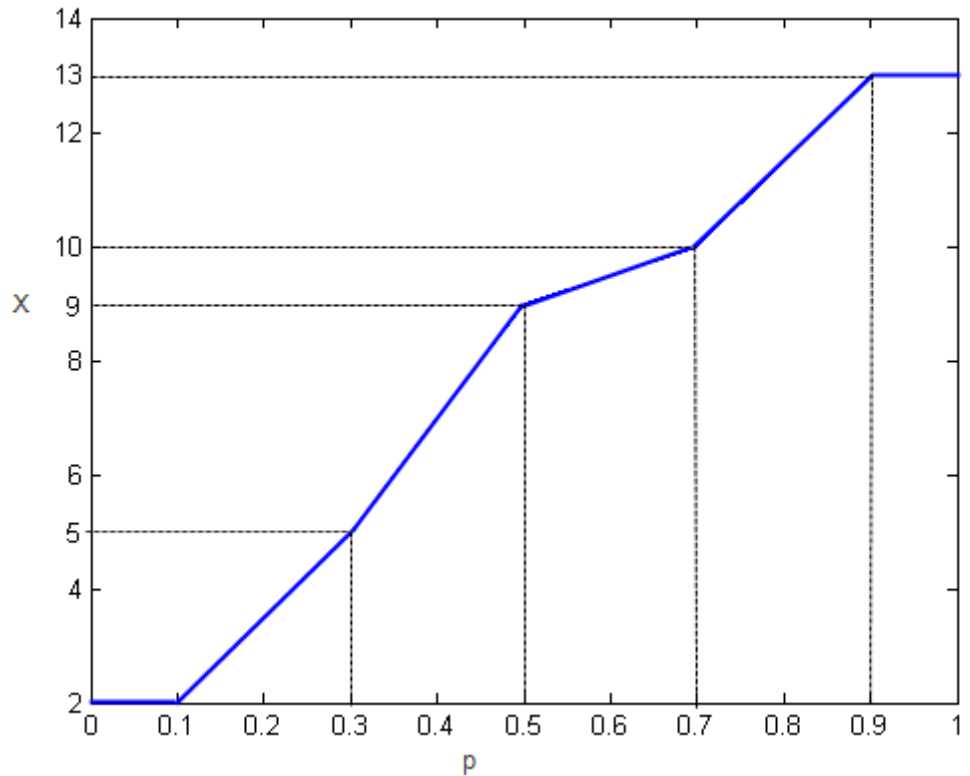
- For a data vector of six elements such as {6, 3, 2, 10, 8, 1}, the sorted elements {1, 2, 3, 6, 8, 10} respectively correspond to the $(0.5/6)$, $(1.5/6)$, $(2.5/6)$, $(3.5/6)$, $(4.5/6)$, and $(5.5/6)$ quantiles.
- For a data vector of five elements such as {2, 10, 5, 9, 13}, the sorted elements {2, 5, 9, 10, 13} respectively correspond to the 0.1, 0.3, 0.5, 0.7, and 0.9 quantiles.

The following figure illustrates this approach for data vector $X = \{2, 10, 5, 9, 13\}$. The first observation corresponds to the cumulative probability $1/5 = 0.2$, the second observation corresponds to the cumulative probability $2/5 = 0.4$, and so on. The step function in this figure shows these cumulative probabilities. `quantile` instead places the observations in midpoints, such that the first corresponds to $0.5/5 = 0.1$, the second corresponds to $1.5/5 = 0.3$, and so on, and then connects these midpoints. The red lines in the following figure connect the midpoints.



Assigning Observations to Quantiles

By switching the axes, as the next figure, you can see the values of the variable X that correspond to the p quantiles.



Quantiles of X

- 2** quantile finds any quantiles between the data values using linear interpolation.

Linear interpolation uses linear polynomials to approximate a function $f(x)$ and construct new data points within the range of a known set of data points. Algebraically, given the data points (x_1, y_1) and (x_2, y_2) , where $y_1 = f(x_1)$ and $y_2 = f(x_2)$, linear interpolation finds $y = f(x)$ for a given x between x_1 and x_2 as follows:

$$y = f(x) = y_1 + \frac{(x - x_1)}{(x_2 - x_1)}(y_2 - y_1).$$

Similarly, if the $1.5/n$ quantile is $y_{1.5/n}$ and the $2.5/n$ quantile is $y_{2.5/n}$, then linear interpolation finds the $2.3/n$ quantile $y_{2.3/n}$ as

$$y_{\frac{2.3}{n}} = y_{\frac{1.5}{n}} + \frac{\left(\frac{2.3}{n} - \frac{1.5}{n}\right)}{\left(\frac{2.5}{n} - \frac{1.5}{n}\right)} \left(y_{\frac{2.5}{n}} - y_{\frac{1.5}{n}} \right).$$

3 quantile assigns the first and last values of X to the quantiles for probabilities less than $(0.5/n)$ and greater than $([n-0.5]/n)$, respectively.

See Also

quantile | prctile | median

Exploratory Analysis of Data

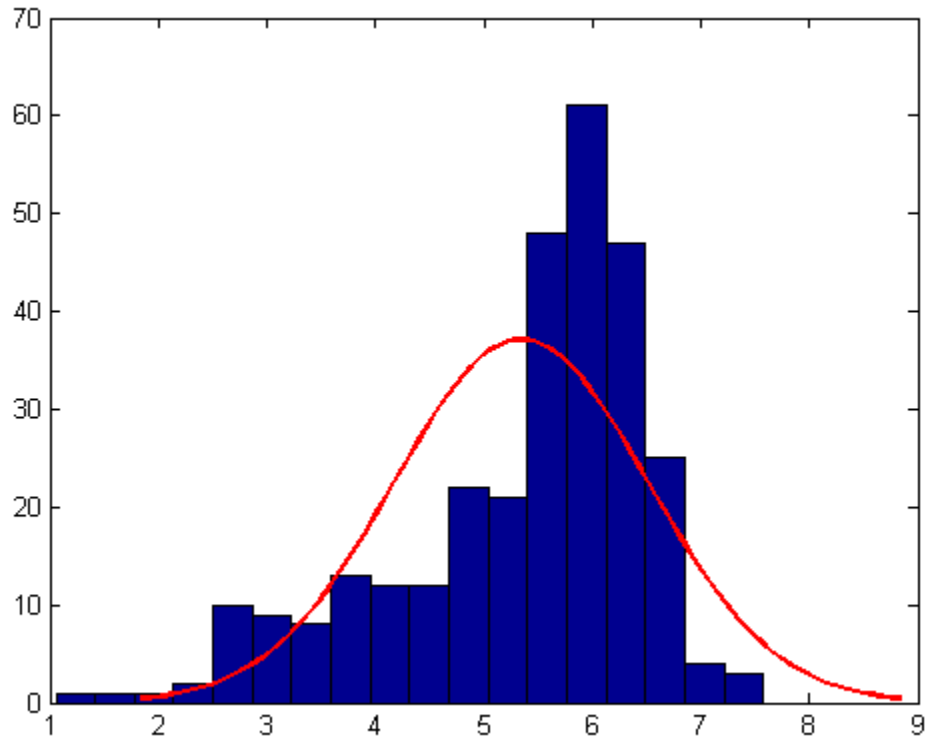
This example shows how to explore the distribution of data using descriptive statistics.

Generate sample data.

```
rng('default') % for reproducibility  
x = [normrnd(4,1,1,100) normrnd(6,0.5,1,200)];
```

Create a histogram of data with normal density fit.

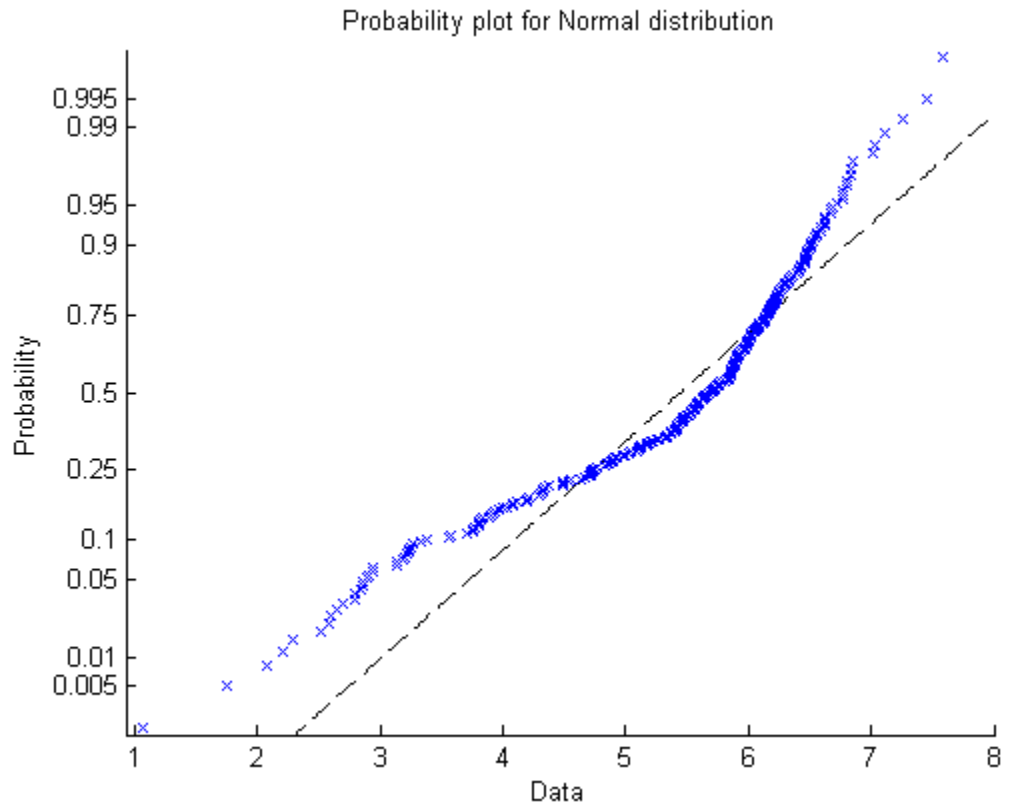
```
histfit(x)
```



The distribution of the data seems left skewed and normal distribution does not look like a good fit to this distribution.

Obtain a normal probability plot.

```
probplot('normal',x)
```



This probability plot also clearly shows the deviation of data from normality.

Compute quantiles of data.

```
p = 0:0.25:1;  
y = quantile(x,p);
```

```
z = [p;y]
```

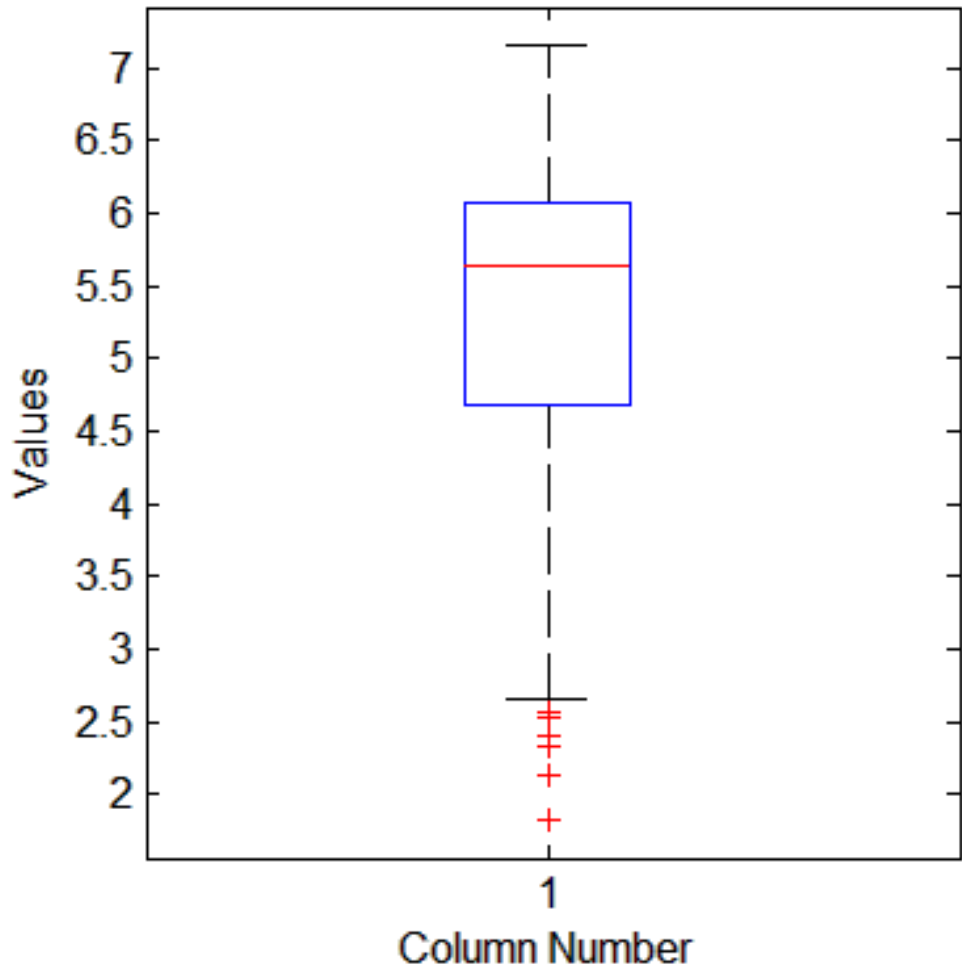
```
z =
```

```
      0      0.2500      0.5000      0.7500      1.0000
1.0557  4.7375  5.6872  6.1526  7.5784
```

Plot a box plot.

A box plot helps to visualize the statistics.

```
boxplot(x)
```



You can also see the 0.25, 0.5, and 0.75 quantiles in the box plot. The long lower tail and plus signs also show the lack of symmetry in the sample values.

Compute the mean and median of data.

`y = [mean(x) median(x)]`

`y =`


```
5.3438    5.6872
```

The mean and median values seem close to each other, but a mean smaller than the median usually flags left skewness of the data.

Compute the skewness and kurtosis of data.

```
y = [skewness(x) kurtosis(x)]
```

```
y =
```

```
-1.0417    3.5895
```

A negative skewness value means the data is left skewed. The data has a larger peakedness than a normal distribution because the kurtosis value is greater than 3.

Check for outliers.

Compute the z-scores.

```
Z = zscore(x);
```

Find the z-scores that are greater than 3 or less than -3.

```
find(abs(Z)>3);
```

```
ans =
```

```
3    35
```

The 3rd and 35th observations might be outliers.

See Also

```
quantile | prctile | histfit | boxplot | mean | median | kurtosis  
| skewness
```

Concepts

- “Box Plots” on page 4-6
- “Measures of Central Tendency” on page 3-3
- “Measures of Dispersion” on page 3-5
- “Quantiles and Percentiles” on page 3-7

Resampling Statistics

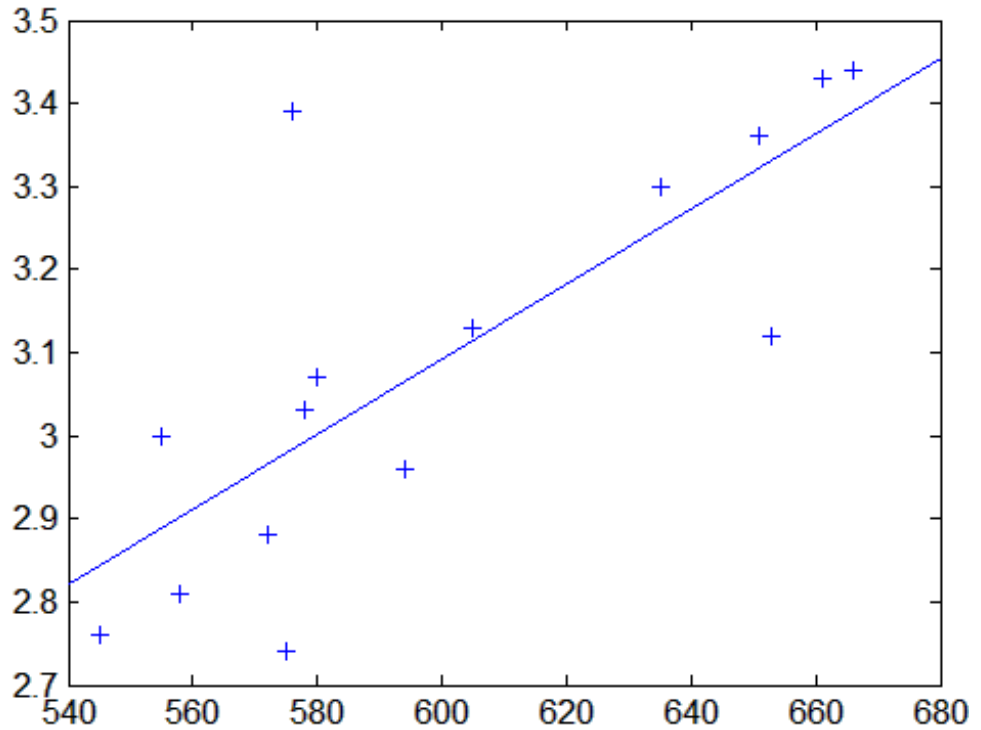
In this section...
“Bootstrap” on page 3-16
“Jackknife” on page 3-19
“Parallel Computing Support for Resampling Methods” on page 3-20

Bootstrap

The *bootstrap* procedure involves choosing random samples with replacement from a data set and analyzing each sample the same way. Sampling with replacement means that each observation is selected separately at random from the original dataset. So a particular data point from the original data set could appear multiple times in a given bootstrap sample. The number of elements in each bootstrap sample equals the number of elements in the original data set. The range of sample estimates you obtain enables you to establish the uncertainty of the quantity you are estimating.

This example from Efron and Tibshirani [33] compares Law School Admission Test (LSAT) scores and subsequent law school grade point average (GPA) for a sample of 15 law schools.

```
load lawdata
plot(lsat,gpa, '+')
lsline
```



The least-squares fit line indicates that higher LSAT scores go with higher law school GPAs. But how certain is this conclusion? The plot provides some intuition, but nothing quantitative.

You can calculate the correlation coefficient of the variables using the `corr` function.

```
rho_hat = corr(lsat, gpa)
rho_hat =
    0.7764
```

Now you have a number describing the positive connection between LSAT and GPA; though it may seem large, you still do not know if it is statistically significant.

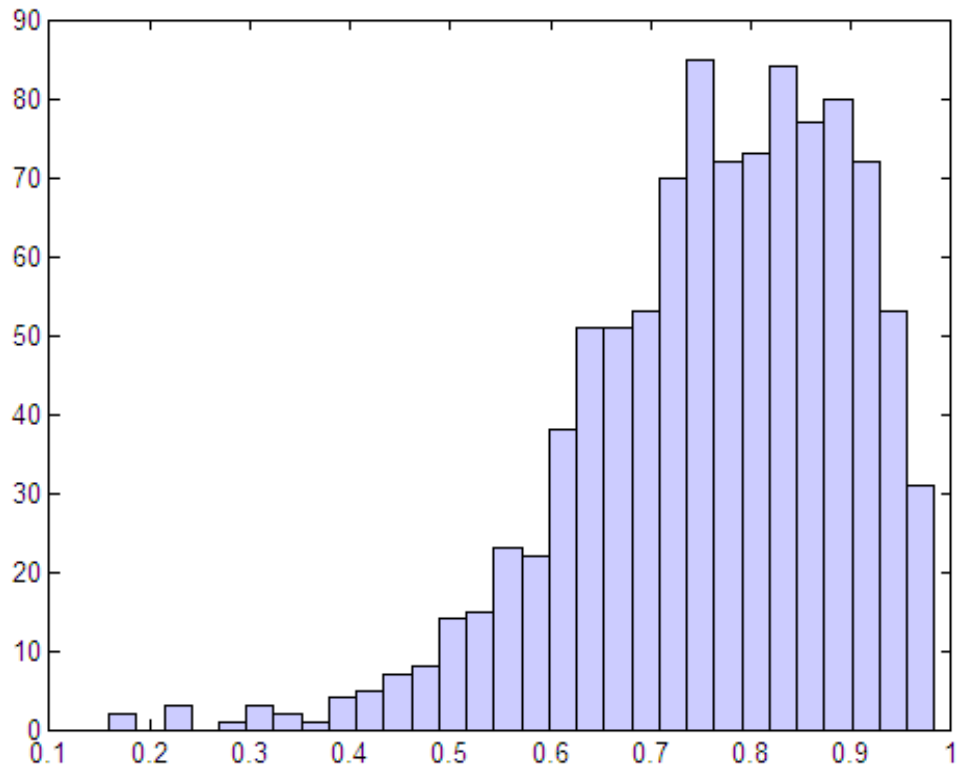
Using the `bootstrp` function you can resample the `lsat` and `gpa` vectors as many times as you like and consider the variation in the resulting correlation coefficients.

Here is an example.

```
rhos1000 = bootstrp(1000, 'corr', lsat, gpa);
```

This command resamples the `lsat` and `gpa` vectors 1000 times and computes the `corr` function on each sample. Here is a histogram of the result.

```
hist(rhos1000, 30)  
set(get(gca, 'Children'), 'FaceColor', [.8 .8 1])
```



Nearly all the estimates lie on the interval [0.4 1.0].

It is often desirable to construct a confidence interval for a parameter estimate in statistical inferences. Using the `bootci` function, you can use bootstrapping to obtain a confidence interval. The confidence interval for the `lsat` and `gpa` data is computed as:

```
ci = bootci(5000,@corr,lsat,gpa)
```

```
ci =  
    0.3313  
    0.9427
```

Therefore, a 95% confidence interval for the correlation coefficient between LSAT and GPA is [0.33 0.94]. This is strong quantitative evidence that LSAT and subsequent GPA are positively correlated. Moreover, this evidence does not require any strong assumptions about the probability distribution of the correlation coefficient.

Although the `bootci` function computes the Bias Corrected and accelerated (BCa) interval as the default type, it is also able to compute various other types of bootstrap confidence intervals, such as the studentized bootstrap confidence interval.

Jackknife

Similar to the bootstrap is the *jackknife*, which uses resampling to estimate the bias of a sample statistic. Sometimes it is also used to estimate standard error of the sample statistic. The jackknife is implemented by the Statistics Toolbox function `jackknife`.

The jackknife resamples systematically, rather than at random as the bootstrap does. For a sample with n points, the jackknife computes sample statistics on n separate samples of size $n-1$. Each sample is the original data with a single observation omitted.

In the previous bootstrap example you measured the uncertainty in estimating the correlation coefficient. You can use the jackknife to estimate the bias, which is the tendency of the sample correlation to over-estimate or under-estimate the true, unknown correlation. First compute the sample correlation on the data:

```
load lawdata
```

```
rhohat = corr(lsat,gpa)
```

```
rhohat =  
    0.7764
```

Next compute the correlations for jackknife samples, and compute their mean:

```
jackrho = jackknife(@corr,lsat,gpa);  
meanrho = mean(jackrho)
```

```
meanrho =  
    0.7759
```

Now compute an estimate of the bias:

```
n = length(lsat);  
biasrho = (n-1) * (meanrho-rhohat)
```

```
biasrho =  
   -0.0065
```

The sample correlation probably underestimates the true correlation by about this amount.

Parallel Computing Support for Resampling Methods

For information on computing resampling statistics in parallel, see Parallel Computing Toolbox™.

Data with Missing Values

Many data sets have one or more missing values. It is convenient to code missing values as NaN (Not a Number) to preserve the structure of data sets across multiple variables and observations.

For example:

```
X = magic(3);
X([1 5]) = [NaN NaN]
X =
    NaN     1     6
     3    NaN     7
     4     9     2
```

Normal MATLAB arithmetic operations yield NaN values when operands are NaN:

```
s1 = sum(X)
s1 =
    NaN    NaN    15
```

Removing the NaN values would destroy the matrix structure. Removing the rows containing the NaN values would discard data. Statistics Toolbox functions in the following table remove NaN values only for the purposes of computation.

Function	Description
nancov	Covariance matrix, ignoring NaN values
nanmax	Maximum, ignoring NaN values
nanmean	Mean, ignoring NaN values
nanmedian	Median, ignoring NaN values
nanmin	Minimum, ignoring NaN values
nanstd	Standard deviation, ignoring NaN values
nansum	Sum, ignoring NaN values
nanvar	Variance, ignoring NaN values

For example:

```
s2 = nansum(X)
s2 =
     7     10     15
```

Other Statistics Toolbox functions also ignore NaN values. These include `iqr`, `kurtosis`, `mad`, `prctile`, `range`, `skewness`, and `trimmean`.

Statistical Visualization

- “Introduction to Statistical Visualization” on page 4-2
- “Scatter Plots” on page 4-3
- “Box Plots” on page 4-6
- “Distribution Plots” on page 4-8

Introduction to Statistical Visualization

Statistics Toolbox data visualization functions add to the extensive graphics capabilities already in MATLAB.

- Scatter plots are a basic visualization tool for multivariate data. They are used to identify relationships among variables. Grouped versions of these plots use different plotting symbols to indicate group membership. The `gname` function is used to label points on these plots with a text label or an observation number.
- Box plots display a five-number summary of a set of data: the median, the two ends of the interquartile range (the box), and two extreme values (the whiskers) above and below the box. Because they show less detail than histograms, box plots are most useful for side-by-side comparisons of two distributions.
- Distribution plots help you identify an appropriate distribution family for your data. They include normal and Weibull probability plots, quantile-quantile plots, and empirical cumulative distribution plots.

Advanced Statistics Toolbox visualization functions are available for specialized statistical analyses.

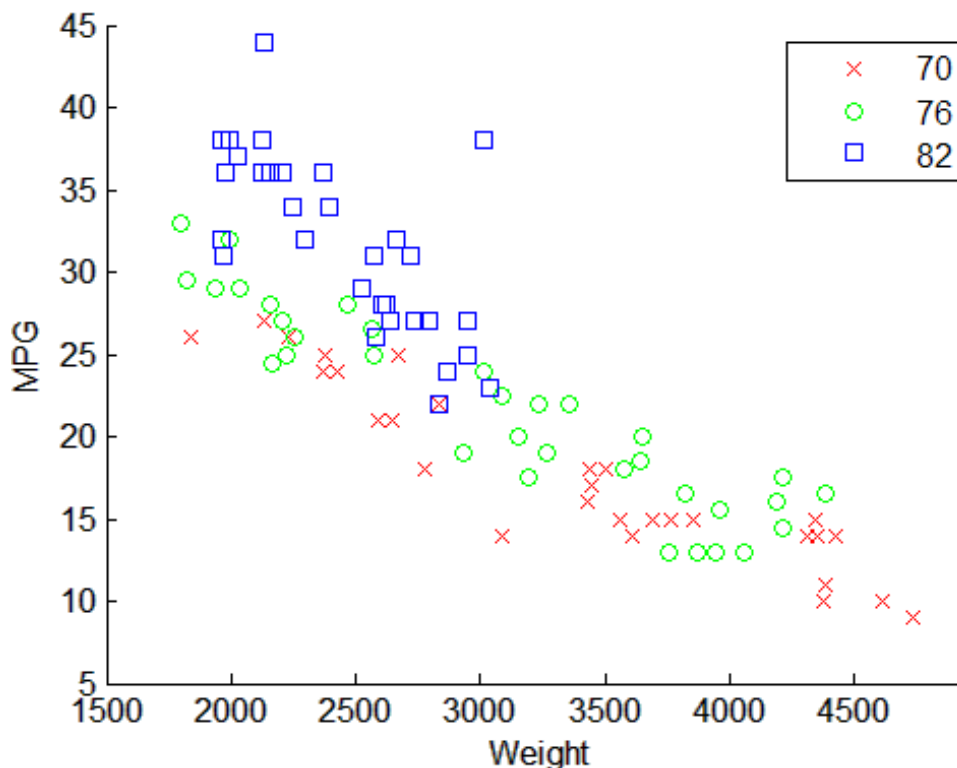
Scatter Plots

A scatter plot is a simple plot of one variable against another. The MATLAB functions `plot` and `scatter` produce scatter plots. The MATLAB function `plotmatrix` can produce a matrix of such plots showing the relationship between several pairs of variables.

Statistics Toolbox functions `gscatter` and `gplotmatrix` produce grouped versions of these plots. These are useful for determining whether the values of two variables or the relationship between those variables is the same in each group.

Suppose you want to examine the weight and mileage of cars from three different model years.

```
load carsmall
gscatter(Weight,MPG,Model_Year,' ','xos')
```



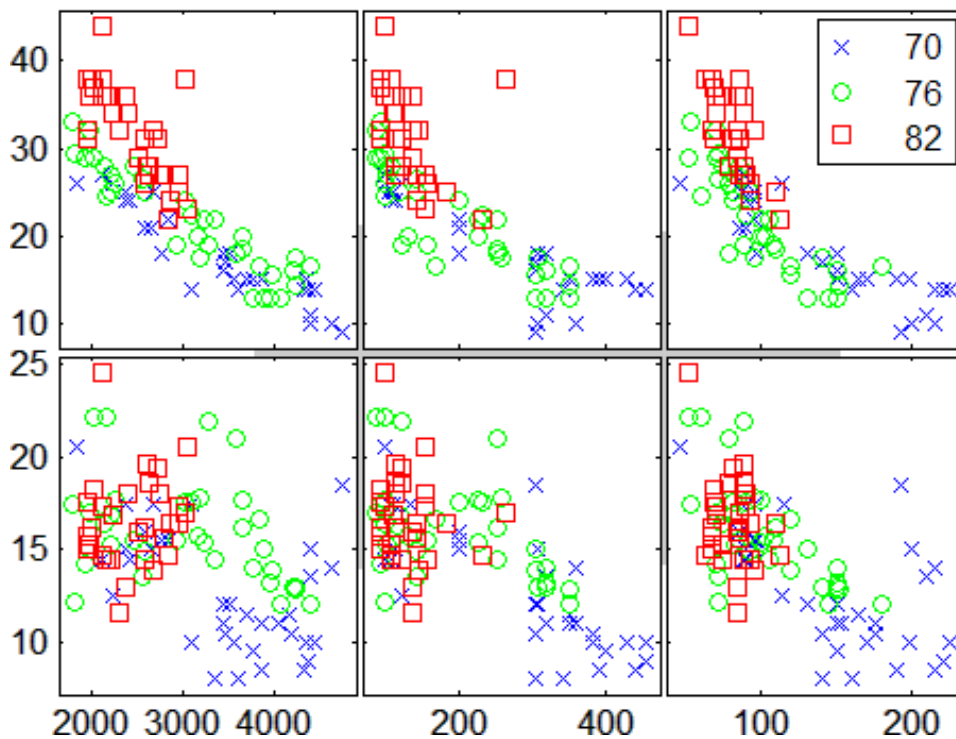
This shows that not only is there a strong relationship between the weight of a car and its mileage, but also that newer cars tend to be lighter and have better gas mileage than older cars.

The default arguments for `gscatter` produce a scatter plot with the different groups shown with the same symbol but different colors. The last two arguments above request that all groups be shown in default colors and with different symbols.

The `carsmall` data set contains other variables that describe different aspects of cars. You can examine several of them in a single display by creating a grouped plot matrix.

```
xvars = [Weight Displacement Horsepower];  
yvars = [MPG Acceleration];
```

```
gplotmatrix(xvars,yvars,Model_Year,' ','xos')
```



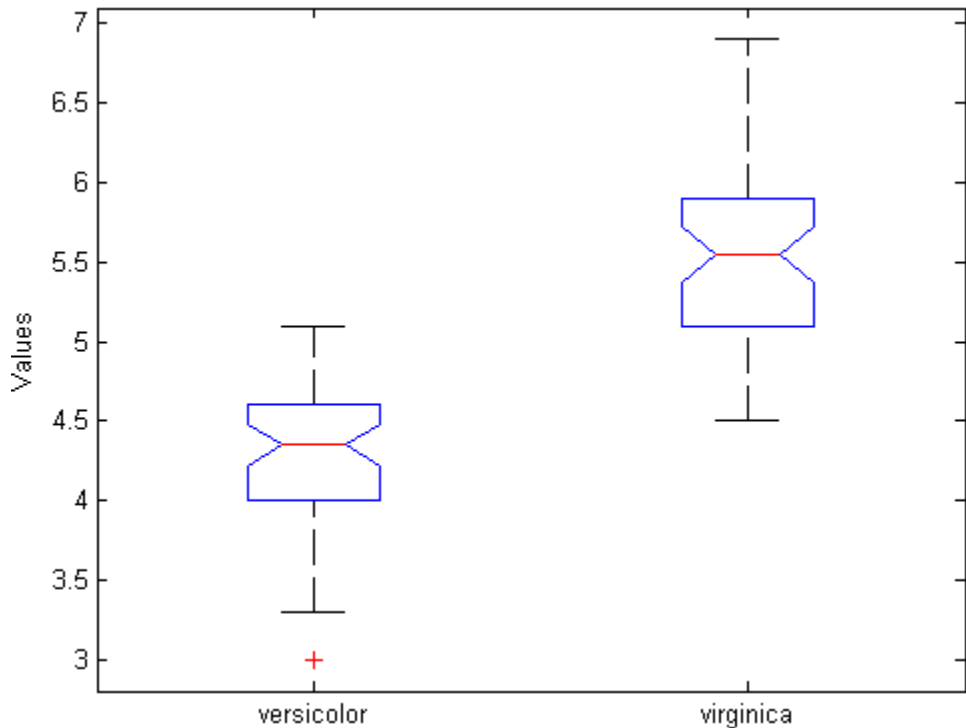
The upper right subplot displays MPG against Horsepower, and shows that over the years the horsepower of the cars has decreased but the gas mileage has improved.

The `gplotmatrix` function can also graph all pairs from a single list of variables, along with histograms for each variable. See “MANOVA” on page 8-39.

Box Plots

The graph below, created with the `boxplot` command, compares petal lengths in samples from two species of iris.

```
load fisheriris
s1 = meas(51:100,3);
s2 = meas(101:150,3);
boxplot([s1 s2], 'notch', 'on', ...
        'labels', {'versicolor', 'virginica'})
```



This plot has the following features:

- The tops and bottoms of each “box” are the 25th and 75th percentiles of the samples, respectively. The distances between the tops and bottoms are the interquartile ranges.

- The line in the middle of each box is the sample median. If the median is not centered in the box, it shows sample skewness.
- The whiskers are lines extending above and below each box. Whiskers are drawn from the ends of the interquartile ranges to the furthest observations within the whisker length (the *adjacent values*).
- Observations beyond the whisker length are marked as outliers. By default, an outlier is a value that is more than 1.5 times the interquartile range away from the top or bottom of the box, but this value can be adjusted with additional input arguments. Outliers are displayed with a red + sign.
- Notches display the variability of the median between samples. The width of a notch is computed so that box plots whose notches do not overlap (as above) have different medians at the 5% significance level. The significance level is based on a normal distribution assumption, but comparisons of medians are reasonably robust for other distributions. Comparing box-plot medians is like a visual hypothesis test, analogous to the t test used for means.

Distribution Plots

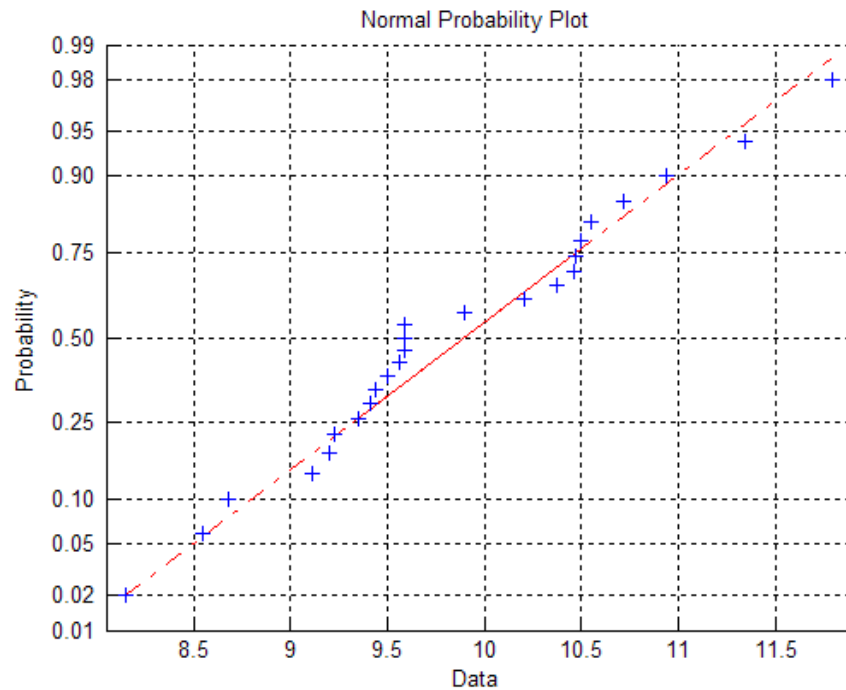
In this section...
“Normal Probability Plots” on page 4-8
“Quantile-Quantile Plots” on page 4-10
“Cumulative Distribution Plots” on page 4-12
“Other Probability Plots” on page 4-14

Normal Probability Plots

Normal probability plots are used to assess whether data comes from a normal distribution. Many statistical procedures make the assumption that an underlying distribution is normal, so normal probability plots can provide some assurance that the assumption is justified, or else provide a warning of problems with the assumption. An analysis of normality typically combines normal probability plots with hypothesis tests for normality.

The following example shows a normal probability plot created with the `normplot` function.

```
x = normrnd(10,1,25,1);  
normplot(x)
```

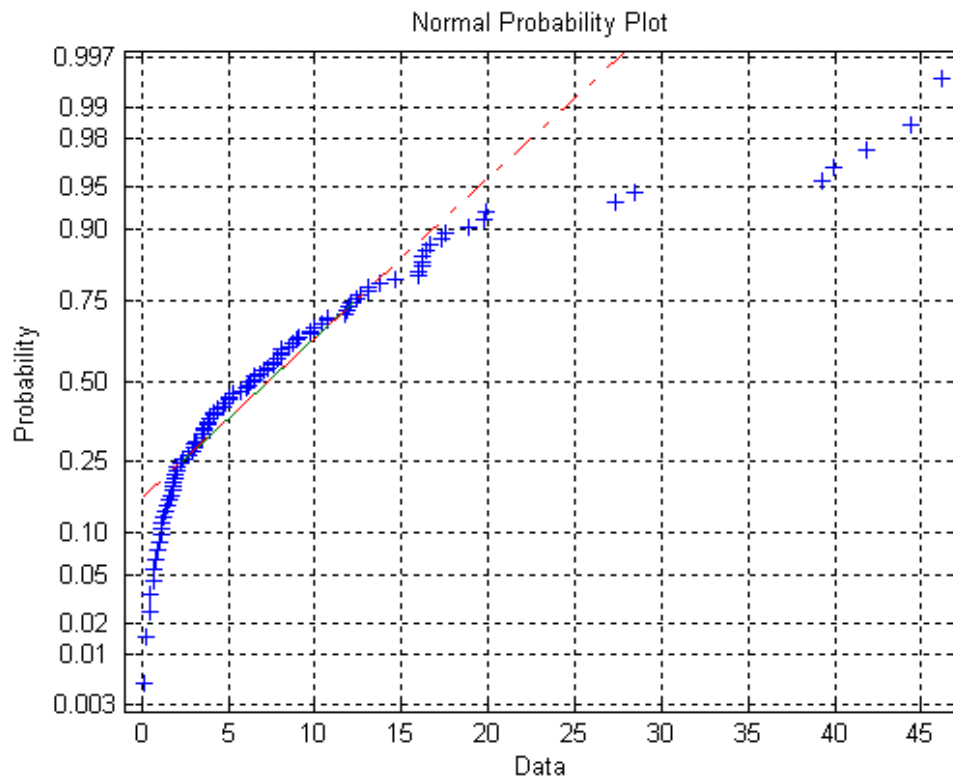
The plus signs plot the empirical probability versus the data value for each point in the data. A solid line connects the 25th and 75th percentiles in the data, and a dashed line extends it to the ends of the data. The y -axis values are probabilities from zero to one, but the scale is not linear. The distance between tick marks on the y -axis matches the distance between the quantiles of a normal distribution. The quantiles are close together near the median (probability = 0.5) and stretch out symmetrically as you move away from the median.

In a normal probability plot, if all the data points fall near the line, an assumption of normality is reasonable. Otherwise, the points will curve away from the line, and an assumption of normality is not justified.

For example:

```
x = exprnd(10,100,1);
```

```
normplot(x)
```



The plot is strong evidence that the underlying distribution is not normal.

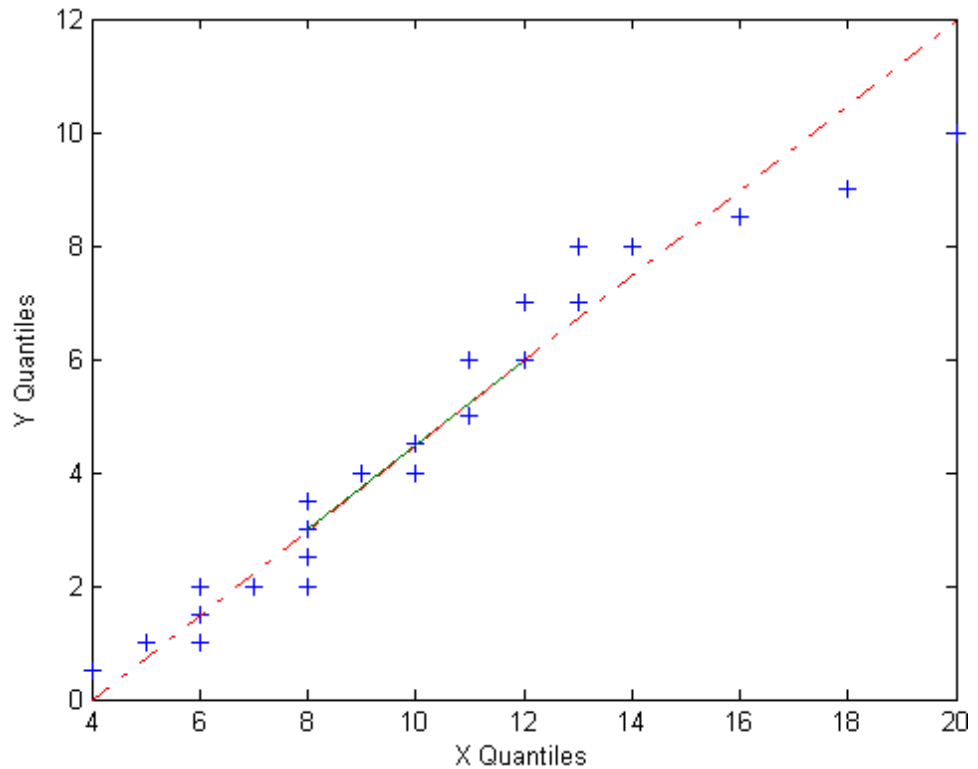
Quantile-Quantile Plots

Quantile-quantile plots are used to determine whether two samples come from the same distribution family. They are scatter plots of quantiles computed from each sample, with a line drawn between the first and third quartiles. If the data falls near the line, it is reasonable to assume that the two samples come from the same distribution. The method is robust with respect to changes in the location and scale of either distribution.

To create a quantile-quantile plot, use the `qqplot` function.

The following example shows a quantile-quantile plot of two samples from Poisson distributions.

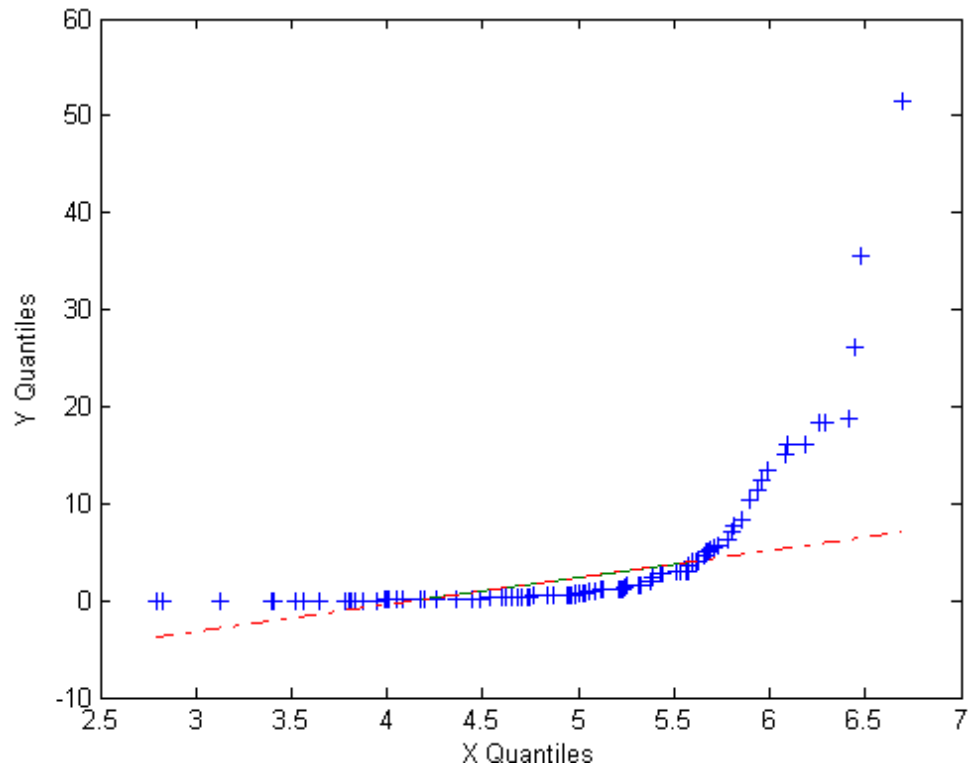
```
x = poissrnd(10,50,1);  
y = poissrnd(5,100,1);  
qqplot(x,y);
```



Even though the parameters and sample sizes are different, the approximate linear relationship suggests that the two samples may come from the same distribution family. As with normal probability plots, hypothesis tests can provide additional justification for such an assumption. For statistical procedures that depend on the two samples coming from the same distribution, however, a linear quantile-quantile plot is often sufficient.

The following example shows what happens when the underlying distributions are not the same.

```
x = normrnd(5,1,100,1);  
y = wblrnd(2,0.5,100,1);  
qqplot(x,y);
```



These samples clearly are not from the same distribution family.

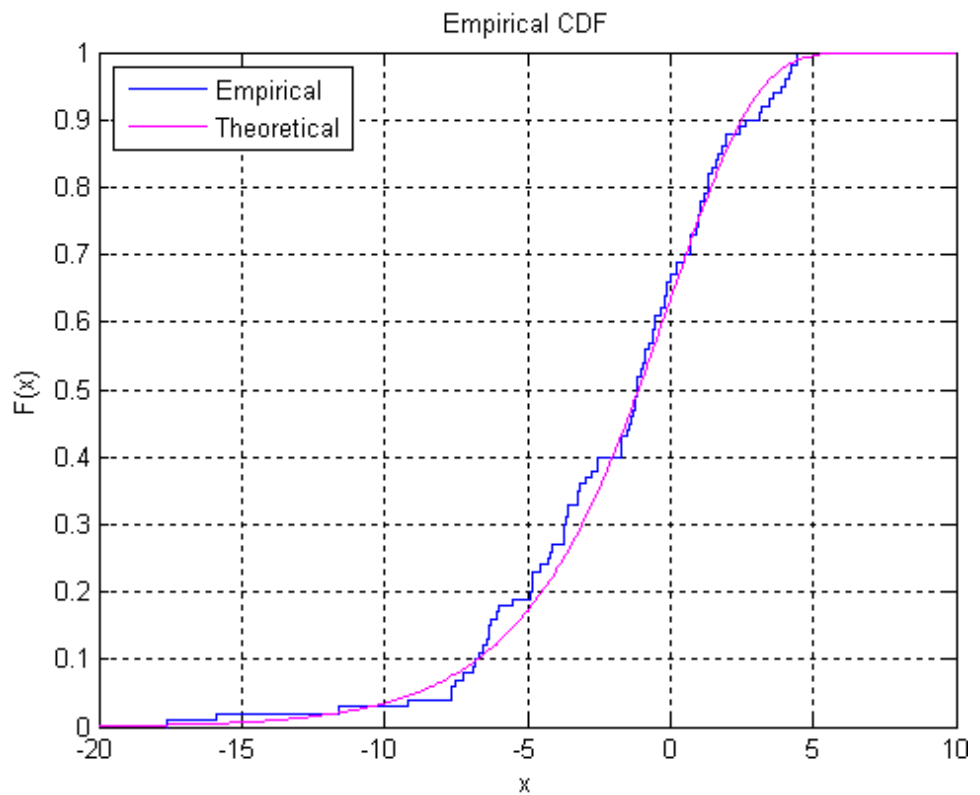
Cumulative Distribution Plots

An empirical cumulative distribution function (cdf) plot shows the proportion of data less than each x value, as a function of x . The scale on the y -axis is linear; in particular, it is not scaled to any particular distribution. Empirical cdf plots are used to compare data cdfs to cdfs for particular distributions.

To create an empirical cdf plot, use the `cdfplot` function (or `ecdf` and `stairs`).

The following example compares the empirical cdf for a sample from an extreme value distribution with a plot of the cdf for the sampling distribution. In practice, the sampling distribution would be unknown, and would be chosen to match the empirical cdf.

```
y = evrnd(0,3,100,1);  
cdfplot(y)  
hold on  
x = -20:0.1:10;  
f = evcdf(x,0,3);  
plot(x,f,'m')  
legend('Empirical','Theoretical','Location','NW')
```



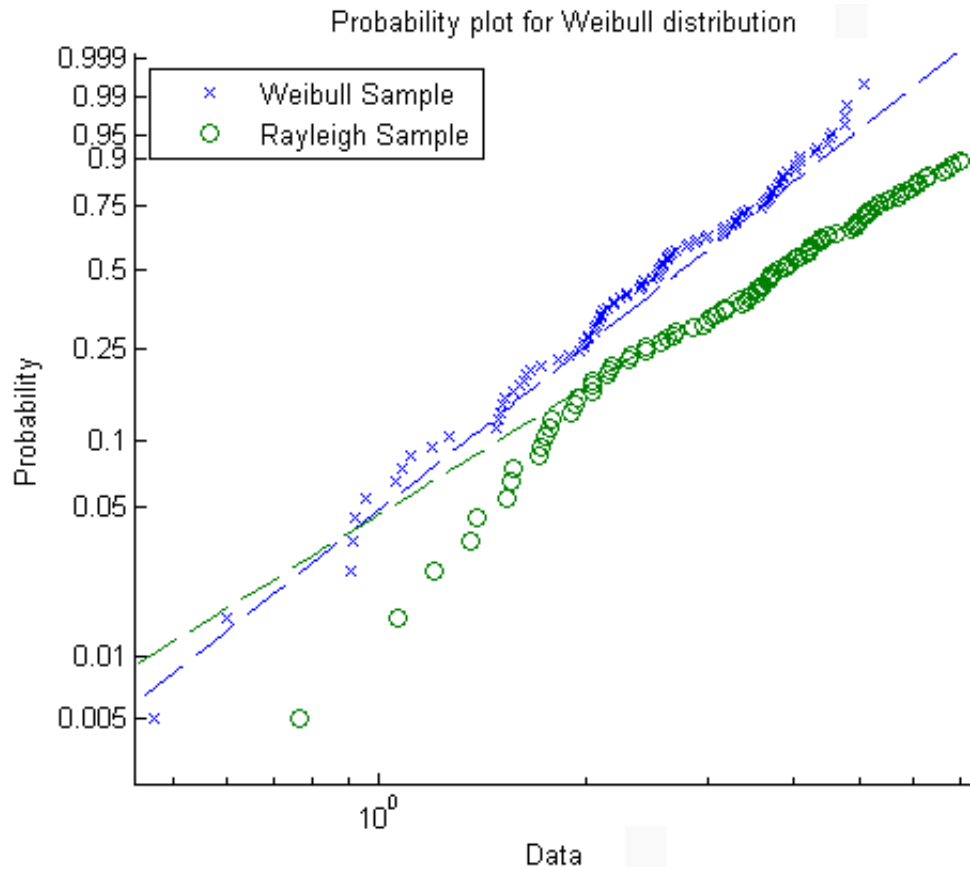
Other Probability Plots

A probability plot, like the normal probability plot, is just an empirical cdf plot scaled to a particular distribution. The y -axis values are probabilities from zero to one, but the scale is not linear. The distance between tick marks is the distance between quantiles of the distribution. In the plot, a line is drawn between the first and third quartiles in the data. If the data falls near the line, it is reasonable to choose the distribution as a model for the data.

To create probability plots for different distributions, use the `probplot` function.

For example, the following plot assesses two samples, one from a Weibull distribution and one from a Rayleigh distribution, to see if they may have come from a Weibull population.

```
x1 = wblrnd(3,3,100,1);  
x2 = raylrnd(3,100,1);  
probplot('weibull',[x1 x2])  
legend('Weibull Sample','Rayleigh Sample','Location','NW')
```



The plot gives justification for modeling the first sample with a Weibull distribution; much less so for the second sample.

A distribution analysis typically combines probability plots with hypothesis tests for a particular distribution.

Probability Distributions

- “Using Probability Distributions” on page 5-2
- “Supported Distributions” on page 5-3
- “Working with Distributions Through GUIs” on page 5-10
- “Statistics Toolbox Distribution Functions” on page 5-53
- “Using Probability Distribution Objects” on page 5-85
- “Probability Distributions Used for Multivariate Modeling” on page 5-100

Using Probability Distributions

Probability distributions are theoretical distributions based on assumptions about a source population. They assign probability to the event that a random variable takes on a specific, discrete value, or falls within a specified range of continuous values. There are two main types of models:

- **Parametric Models**—Choose a model based on a parametric family of probability distributions and then adjust the parameters to fit the data. For information on supported parametric distributions, see “Parametric Distributions” on page 5-4.
- **Nonparametric Models**—When data or statistics do not follow any standard probability distribution, *nonparametric models* may be appropriate. For information on supported nonparametric distributions, see “Nonparametric Distributions” on page 5-9.

The Statistics Toolbox provides several ways of working with both parametric and nonparametric probability distributions:

- **Graphic User Interfaces (GUIs)**—Interact with the distributions to visualize distributions, fit a distribution to your data, or generate random data using a specific distribution. For more information, see “Working with Distributions Through GUIs” on page 5-10.
- **Command Line Functions**—Use command-line functions to further explore the distributions, fit relevant models to your data, or generate random data. For more information on using functions, see “Statistics Toolbox Distribution Functions” on page 5-53.
- **Distribution Objects**—Use objects to explore and fit your data to a distribution, save the results to a single entity, and generate random data from the resulting parameters. For more information, see “Using Probability Distribution Objects” on page 5-85.

Supported Distributions

In this section...
“Parametric Distributions” on page 5-4
“Nonparametric Distributions” on page 5-9

Probability distributions supported by the Statistics Toolbox are cross-referenced with their supporting functions and GUIs in the following tables. The tables use the following abbreviations for distribution functions:

- **pdf** — Probability density functions
- **cdf** — Cumulative distribution functions
- **inv** — Inverse cumulative distribution functions
- **stat** — Distribution statistics functions
- **fit** — Distribution fitting functions
- **like** — Negative log-likelihood functions
- **rnd** — Random number generators

For more detailed explanations of each supported distribution, see Appendix B, “Distribution Reference”.

Parametric Distributions

Continuous Distributions (Data)

Name	pdf	cdf	inv	stat	fit	like	rnd
Beta	betapdf, pdf	betacdf, cdf	betainv, icdf	betastat	betafit, fitdist, mle, dfittool	betalike	betarnd, random, randtool
Birnbaum-Saunders	pdf	cdf	icdf		mle, fitdist, dfittool		random
Burr Type XII	pdf	cdf	icdf		mle, fitdist, dfittool		random, randtool
Exponential	exppdf, pdf	expcdf, cdf	expinv, icdf	expstat	expfit, mle, fitdist, dfittool	explike	exprnd, random, randtool
Extreme value	evpdf, pdf	evcdf, cdf	evinv, icdf	evstat	evfit, mle, fitdist, dfittool	evlike	evrnd, random, randtool
Gamma	gampdf, pdf	gamcdf, cdf	gaminv, icdf	gamstat	gamfit, mle, fitdist, dfittool	gamlike	gamrnd, randg, random, randtool
Generalized extreme value	gevpdf, pdf	gevcdf, cdf	gevinv, icdf	gevstat	gevfit, mle, fitdist, dfittool	gevlike	gevrnd, random, randtool
Generalized Pareto	gppdf, pdf	gpcdf, cdf	gpinv, icdf	gpstat	gpfit, mle, fitdist, dfittool	gplike	gprnd, random, randtool

Name	pdf	cdf	inv	stat	fit	like	rnd
Inverse Gaussian	pdf	cdf	icdf		mle, fitdist, dfittool		random
Johnson system					johnsrnd		johnsrnd
Logistic	pdf	cdf	icdf		mle, fitdist, dfittool		random
Loglogistic	pdf	cdf	icdf		mle, fitdist, dfittool		random
Lognormal	lognpdf, pdf	logncdf, cdf	logninv, icdf	lognstat	lognfit, mle, fitdist, dfittool	lognlike	lognrnd, random, randtool
Nakagami	pdf	cdf	icdf		mle, fitdist, dfittool		random
Normal (Gaussian)	normpdf, pdf	normcdf, cdf	norminv, icdf	normstat	normfit, mle, fitdist, dfittool	normlike	normrnd, randn, random, randtool
Pearson system					pearsrnd		pearsrnd
Piecewise	pdf	cdf	icdf		paretotails		random
Rayleigh	raylpdf, pdf	raylcdf, cdf	raylinv, icdf	raylstat	raylfit, mle, fitdist, dfittool		raylrnd, random, randtool
Rician	pdf	cdf	icdf		mle, fitdist, dfittool		random

Name	pdf	cdf	inv	stat	fit	like	rnd
Uniform (continuous)	unifpdf, pdf	unifcdf, cdf	unifinv, icdf	unifstat	unifit, mle		unifrnd, rand, random
Weibull	wblpdf, pdf	wblcdf, cdf	wblinv, icdf	wblstat	wblfit, mle, fitdist, dfittool	wbllike	wblrnd, random

Continuous Distributions (Statistics)

Name	pdf	cdf	inv	stat	fit	like	rnd
Chi-square	chi2pdf, pdf	chi2cdf, cdf	chi2inv, icdf	chi2stat			chi2rnd, random, randtool
F	fpdf, pdf	fcdf, cdf	finv, icdf	fstat			frnd, random, randtool
Noncentral chi-square	ncx2pdf, pdf	ncx2cdf, cdf	ncx2inv, icdf	ncx2stat			ncx2rnd, random, randtool
Noncentral F	ncfpdf, pdf	ncfcdf, cdf	ncfinv, icdf	ncfstat			ncfrnd, random, randtool
Noncentral t	nctpdf, pdf	nctcdf, cdf	nctinv, icdf	nctstat			nctrnd, random, randtool
Student's t	tpdf, pdf	tcdf, cdf	tinu, icdf	tstat			trnd, random, randtool
t location- scale	pdf	cdf	icdf		mle, fitdist, dfittool		random

Discrete Distributions

Name	pdf	cdf	inv	stat	fit	like	rnd
Binomial	binopdf, pdf	binocdf, cdf	binoinv, icdf	binostat	binofit, mle, fitdist, dfittool		binornd, random, randtool
Bernoulli					mle		
Geometric	geopdf, pdf	geocdf, cdf	geoinv, icdf	geostat	mle		geornd, random, randtool
Hypergeometric	hygepdf, pdf	hygecdf, cdf	hygeinv, icdf	hygestat			hygernd, random
Multinomial	mnpdf						mnrnd
Negative binomial	nbinpdf, pdf	nbincdf, cdf	nbininv, icdf	nbinstat	nbinfit, mle, fitdist, dfittool		nbinrnd, random, randtool
Poisson	poisspdf, pdf	poisscdf, cdf	poissinv, icdf	poisstat	poissfit, mle, fitdist, dfittool		poissrnd, random, randtool
Uniform (discrete)	unidpdf, pdf	unidcdf, cdf	unidinv, icdf	unidstat	mle		unidrnd, random, randtool

Multivariate Distributions

Name	pdf	cdf	inv	stat	fit	like	rnd
Gaussian copula	copulapdf	copulacdf		copulastat	copulafit		copularnd
Gaussian mixture	pdf	cdf			fit		random
<i>t</i> copula	copulapdf	copulacdf		copulastat	copulafit		copularnd
Clayton copula	copulapdf	copulacdf		copulastat	copulafit		copularnd
Frank copula	copulapdf	copulacdf		copulastat	copulafit		copularnd
Gumbel copula	copulapdf	copulacdf		copulastat	copulafit		copularnd
Inverse Wishart							iwishrnd
Multivariate normal	mvnpdf	mvncdf					mvnrnd
Multivariate <i>t</i>	mvtpdf	mvtcdf					mvtrnd
Wishart							wishrnd

Nonparametric Distributions

Name	pdf	cdf	inv	stat	fit	like	rnd
Nonparametric	ksdensity	ksdensity	ksdensity		ksdensity, fitdist, dfittool		

Working with Distributions Through GUIs

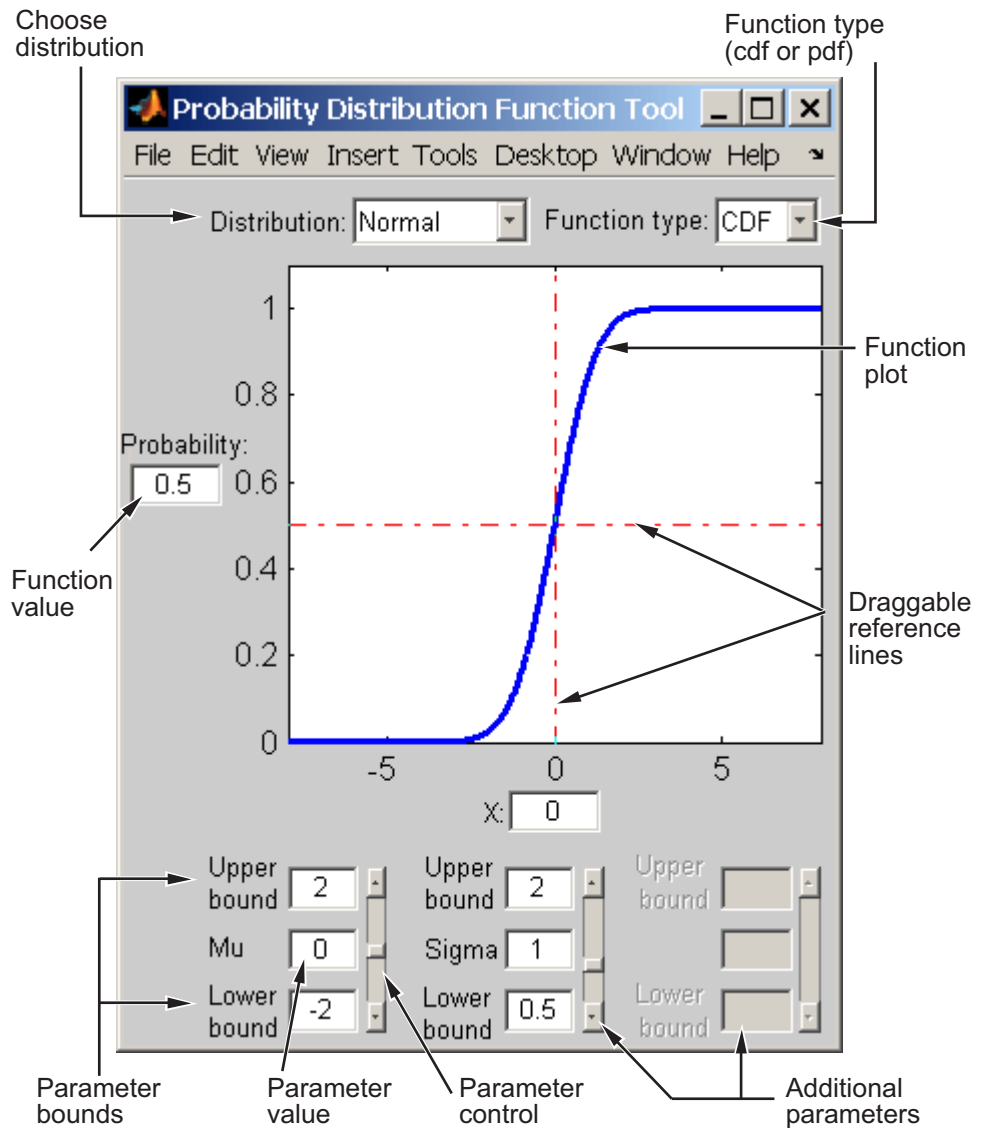
In this section...
“Exploring Distributions” on page 5-10
“Modeling Data Using the Distribution Fitting Tool” on page 5-12
“Custom Distributions Using Distribution Fitting Tool” on page 5-49
“Visually Exploring Random Number Generation” on page 5-50

This section describes Statistics Toolbox GUIs that provide convenient, interactive access to the distribution functions described in “Statistics Toolbox Distribution Functions” on page 5-53.

Exploring Distributions

To interactively see the influence of parameter changes on the shapes of the pdfs and cdfs of supported Statistics Toolbox distributions, use the Probability Distribution Function Tool.

Run the tool by typing `disttool` at the command line.



Start by selecting a distribution. Then choose the function type: probability density function (pdf) or cumulative distribution function (cdf).

After the plot appears, you can

- Calculate a new function value by
 - Typing a new x value in the text box on the x -axis
 - Dragging the vertical reference line.
 - Clicking in the figure where you want the line to be.The new function value appears in the text box to the left of the plot.
- For cdf plots, find critical values corresponding to a specific probability by typing the desired probability in the text box on the y -axis or by dragging the horizontal reference line.
- Use the controls at the bottom of the window to set parameter values for the distribution and to change their upper and lower bounds.

Modeling Data Using the Distribution Fitting Tool

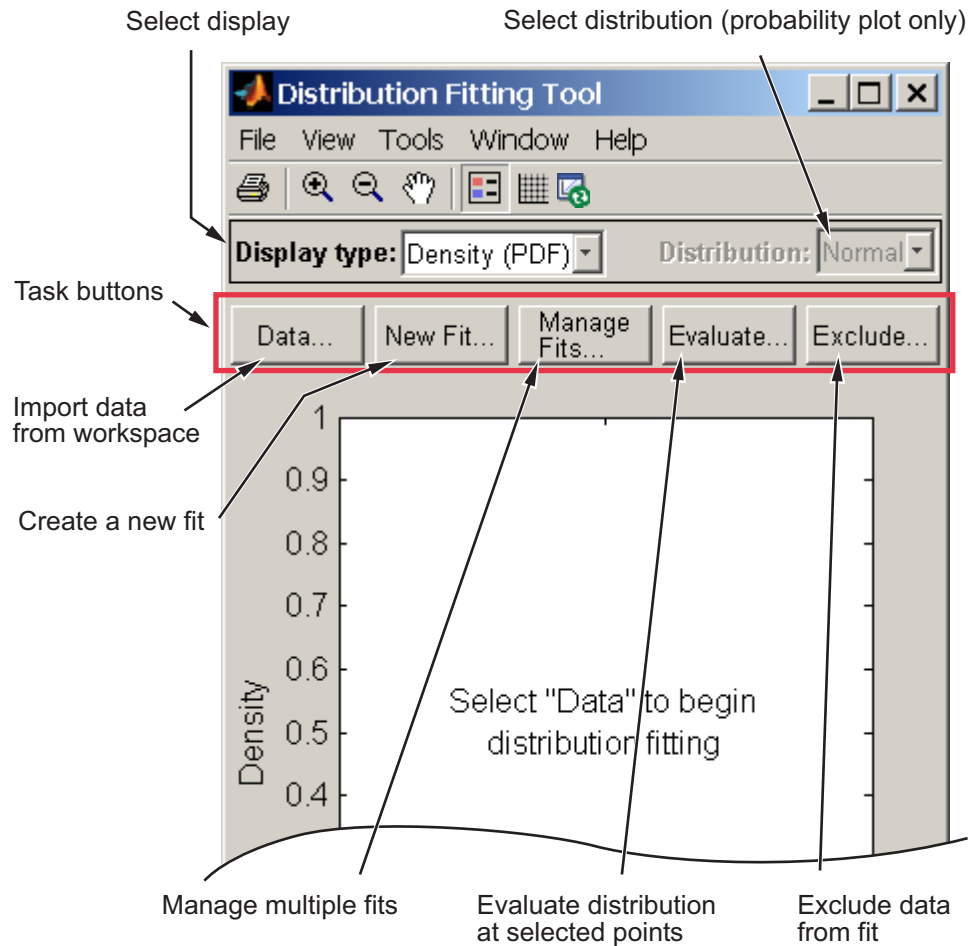
The Distribution Fitting Tool is a GUI for fitting univariate distributions to data. This section describes how to use the Distribution Fitting Tool this tool and covers the following topics:

- “Opening the Distribution Fitting Tool” on page 5-13
- “Creating and Managing Data Sets” on page 5-15
- “Creating a New Fit” on page 5-20
- “Displaying Results” on page 5-26
- “Managing Fits” on page 5-27
- “Evaluating Fits” on page 5-29
- “Excluding Data” on page 5-33
- “Saving and Loading Sessions” on page 5-39
- “Example: Fitting a Distribution” on page 5-40
- “Generating a File to Fit and Plot Distributions” on page 5-47
- “Additional Distributions Available in the Distribution Fitting Tool” on page 5-49

Opening the Distribution Fitting Tool



To open the Distribution Fitting Tool, enter the command

```
dfittool
```



Adjusting the Plot. Buttons at the top of the tool allow you to adjust the plot displayed in this window:

-  — Toggle the legend on (default) or off.

-  — Toggle grid lines on or off (default).
-  — Restore default axes limits.

Displaying the Data. The **Display type** field specifies the type of plot displayed in the main window. Each type corresponds to a probability function, for example, a probability density function. The following display types are available:

- **Density (PDF)** — Display a probability density function (PDF) plot for the fitted distribution.
- **Cumulative probability (CDF)** — Display a cumulative probability plot of the data.
- **Quantile (inverse CDF)** — Display a quantile (inverse CDF) plot.
- **Probability plot** — Display a probability plot.
- **Survivor function** — Display a survivor function plot of the data.
- **Cumulative hazard** — Display a cumulative hazard plot of the data.

Inputting and Fitting Data. The task buttons enable you to perform the tasks necessary to fit distributions to data. Each button opens a new dialog box in which you perform the task. The buttons include:

- **Data** — Import and manage data sets. See “Creating and Managing Data Sets” on page 5-15.
- **New Fit** — Create new fits. See “Creating a New Fit” on page 5-20.
- **Manage Fits** — Manage existing fits. See “Managing Fits” on page 5-27.
- **Evaluate** — Evaluate fits at any points you choose. See “Evaluating Fits” on page 5-29.
- **Exclude** — Create rules specifying which values to exclude when fitting a distribution. See “Excluding Data” on page 5-33.

The display pane displays plots of the data sets and fits you create. Whenever you make changes in one of the dialog boxes, the results in the display pane update.

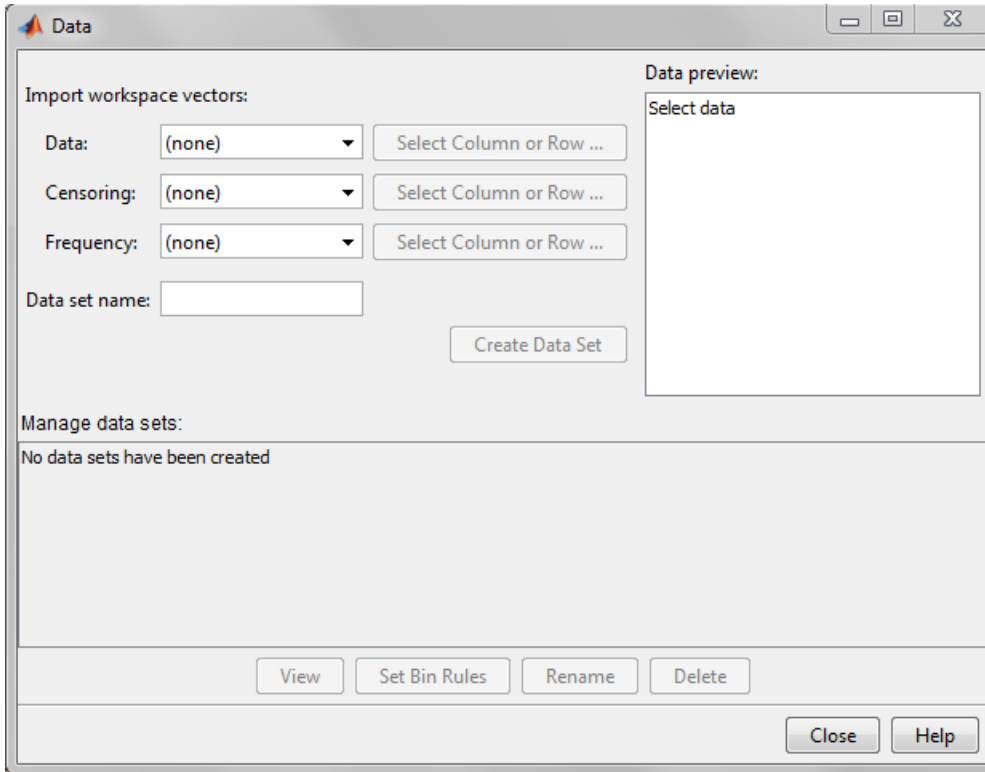
Saving and Customizing Distributions. The Distribution Fitting Tool menus contain items that enable you to do the following:

- Save and load sessions. See “Saving and Loading Sessions” on page 5-39.
- Generate a file with which you can fit distributions to data and plot the results independently of the Distribution Fitting Tool. See “Generating a File to Fit and Plot Distributions” on page 5-47.
- Define and import custom distributions. See “Custom Distributions Using Distribution Fitting Tool” on page 5-49.

Creating and Managing Data Sets

This section describes how to create and manage data sets.

To begin, click the **Data** button in the Distribution Fitting Tool to open the Data dialog box shown in the following figure.



Importing Data. The **Import workspace vectors** pane enables you to create a data set by importing a vector from the MATLAB workspace. The following sections describe the fields in this pane and give appropriate values for vectors imported from the MATLAB workspace:

- **Data** — The drop-down list in the **Data** field contains the names of all matrices and vectors, other than 1-by-1 matrices (scalars) in the MATLAB workspace. Select the array containing the data you want to fit. The actual data you import must be a vector. If you select a matrix in the **Data** field, the first column of the matrix is imported by default. To select a different column or row of the matrix, click **Select Column or Row**. This displays the matrix in the Variables editor, where you can select a row or column by highlighting it with the mouse.

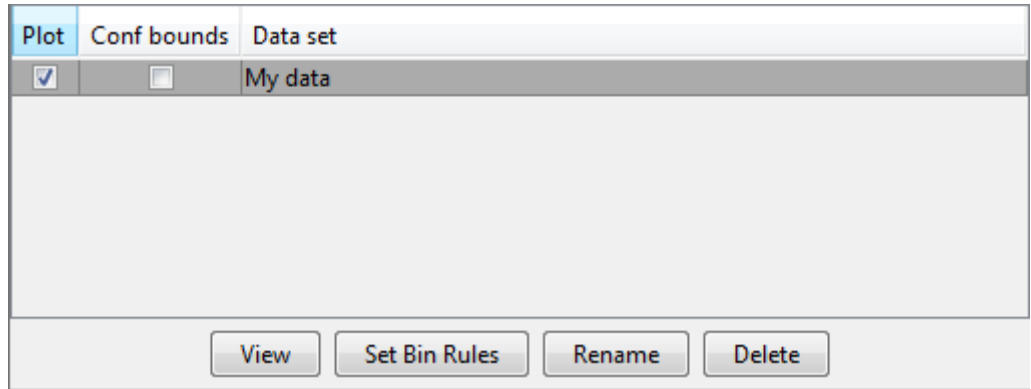
Alternatively, you can enter any valid MATLAB expression in the **Data** field.

When you select a vector in the **Data** field, a histogram of the data appears in the **Data preview** pane.

- **Censoring** — If some of the points in the data set are censored, enter a Boolean vector, of the same size as the data vector, specifying the censored entries of the data. A 1 in the censoring vector specifies that the corresponding entry of the data vector is censored, while a 0 specifies that the entry is not censored. If you enter a matrix, you can select a column or row by clicking **Select Column or Row**. If you do not want to censor any data, leave the **Censoring** field blank.
- **Frequency** — Enter a vector of positive integers of the same size as the data vector to specify the frequency of the corresponding entries of the data vector. For example, a value of 7 in the 15th entry of frequency vector specifies that there are 7 data points corresponding to the value in the 15th entry of the data vector. If all entries of the data vector have frequency 1, leave the **Frequency** field blank.
- **Data set name** — Enter a name for the data set you import from the workspace, such as `My data`.

After you have entered the information in the preceding fields, click **Create Data Set** to create the data set `My data`.

Managing Data Sets. The **Manage data sets** pane enables you to view and manage the data sets you create. When you create a data set, its name appears in the **Data sets** list. The following figure shows the **Manage data sets** pane after creating the data set `My data`.



For each data set in the **Data sets** list, you can:

- Select the **Plot** check box to display a plot of the data in the main Distribution Fitting Tool window. When you create a new data set, **Plot** is selected by default. Clearing the **Plot** check box removes the data from the plot in the main window. You can specify the type of plot displayed in the **Display type** field in the main window.
- If **Plot** is selected, you can also select **Bounds** to display confidence interval bounds for the plot in the main window. These bounds are pointwise confidence bounds around the empirical estimates of these functions. The bounds are only displayed when you set **Display Type** in the main window to one of the following:
 - Cumulative probability (CDF)
 - Survivor function
 - Cumulative hazard

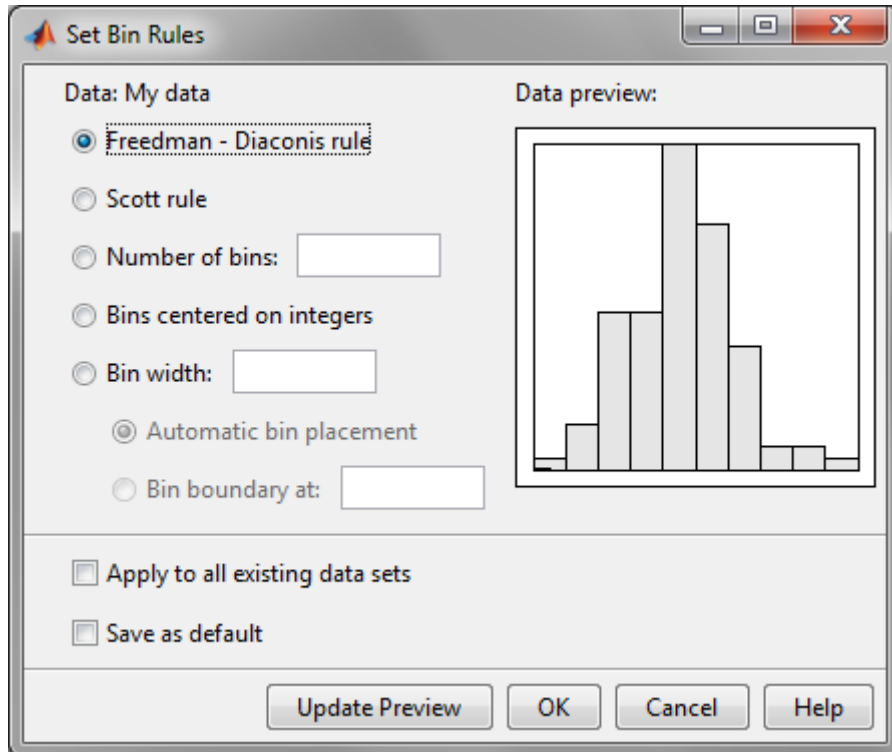
The Distribution Fitting Tool cannot display confidence bounds on density (PDF), quantile (inverse CDF), or probability plots. Clearing the **Bounds** check box removes the confidence bounds from the plot in the main window.

When you select a data set from the list, the following buttons are enabled:

- **View** — Display the data in a table in a new window.
- **Set Bin Rules** — Defines the histogram bins used in a density (PDF) plot.

- **Rename** — Rename the data set.
- **Delete** — Delete the data set.

Setting Bin Rules. To set bin rules for the histogram of a data set, click **Set Bin Rules**. This opens the **Set Bin Width Rules** dialog box.



You can select from the following rules:

- **Freedman-Diaconis rule** — Algorithm that chooses bin widths and locations automatically, based on the sample size and the spread of the data. This rule, which is the default, is suitable for many kinds of data.
- **Scott rule** — Algorithm intended for data that are approximately normal. The algorithm chooses bin widths and locations automatically.
- **Number of bins** — Enter the number of bins. All bins have equal widths.

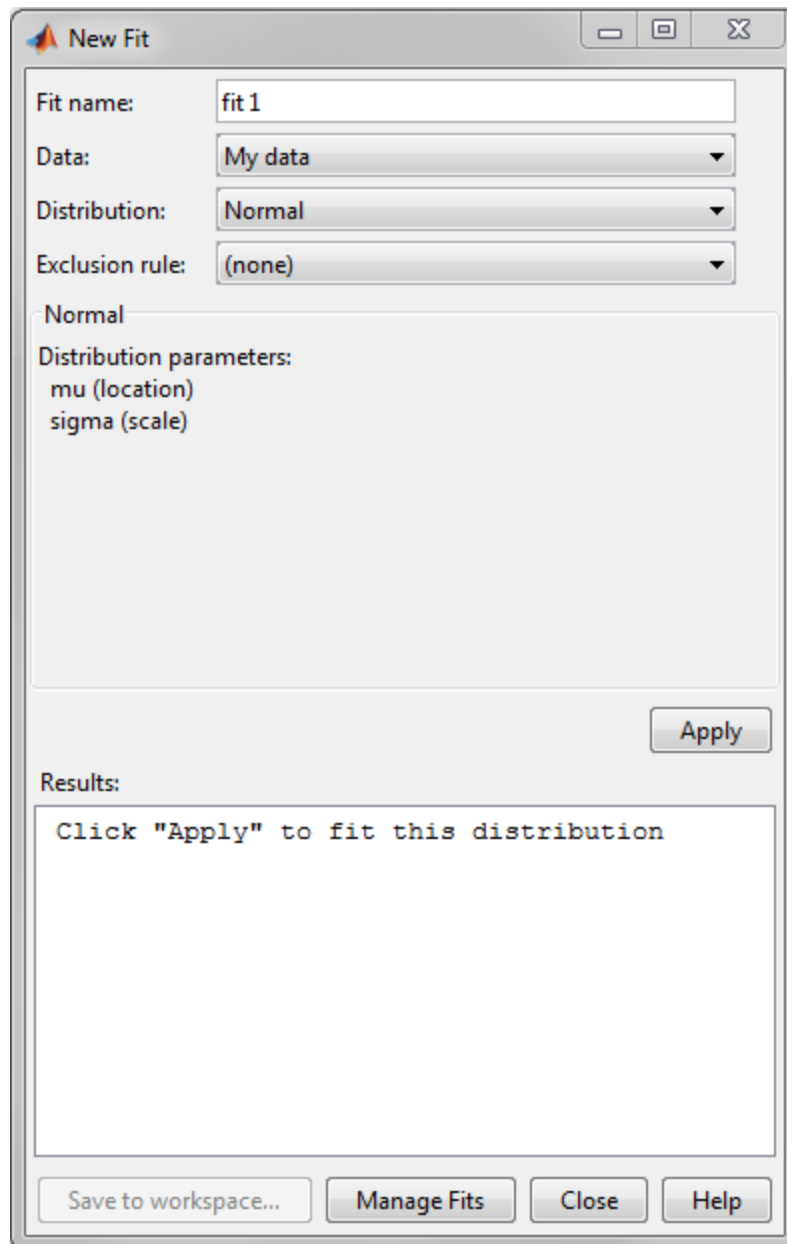
- **Bins centered on integers** — Specifies bins centered on integers.
- **Bin width** — Enter the width of each bin. If you select this option, you can also select:
 - **Automatic bin placement** — Place the edges of the bins at integer multiples of the **Bin width**.
 - **Bin boundary at** — Enter a scalar to specify the boundaries of the bins. The boundary of each bin is equal to this scalar plus an integer multiple of the **Bin width**.

The Set Bin Width Rules dialog box also provides the following options:

- **Apply to all existing data sets** — Apply the rule to all data sets. Otherwise, the rule is only applied to the data set currently selected in the Data dialog box.
- **Save as default** — Apply the current rule to any new data sets that you create. You can also set default bin width rules by selecting **Set Default Bin Rules** from the **Tools** menu in the main window.

Creating a New Fit

This section describes how to create a new fit. To begin, click the **New Fit** button at the top of the main window to open the New Fit dialog box. If you created the data set `My data`, it appears in the **Data** field.



Field Name	Description
Fit Name	Enter a name for the fit in the Fit Name field.
Data	The Data field contains a drop-down list of the data sets you have created. Select the data set to which you want to fit a distribution.
Distribution	<p>Select the type of distribution to fit from the Distribution drop-down list. See “Available Distributions” on page 5-23 for a list of distributions supported by the Distribution Fitting Tool.</p> <p>Only the distributions that apply to the values of the selected data set appear in the Distribution field. For example, positive distributions are not displayed when the data include values that are zero or negative.</p> <p>You can specify either a parametric or a nonparametric distribution. When you select a parametric distribution from the drop-down list, a description of its parameters appears in the Normal pane. The Distribution Fitting Tool estimates these parameters to fit the distribution to the data set. When you select Nonparametric fit, options for the fit appear in the pane, as described in “Further Options for Nonparametric Fits” on page 5-24.</p>
Exclusion rule	Specify a rule to exclude some data in the Exclusion rule field. Create an exclusion rule by clicking Exclude in the Distribution Fitting Tool. For more information, see “Excluding Data” on page 5-33.

Apply the New Fit. Click **Apply** to fit the distribution. For a parametric fit, the **Results** pane displays the values of the estimated parameters. For a nonparametric fit, the **Results** pane displays information about the fit.

When you click **Apply**, the Distribution Fitting Tool displays a plot of the distribution, along with the corresponding data.

Note When you click **Apply**, the title of the dialog box changes to Edit Fit. You can now make changes to the fit you just created and click **Apply** again to save them. After closing the Edit Fit dialog box, you can reopen it from the Fit Manager dialog box at any time to edit the fit.

After applying the fit, you can save the information to the workspace using probability distribution objects by clicking **Save to workspace**. See “Using Probability Distribution Objects” on page 5-85 for more information.

Available Distributions. This section lists the distributions available in the Distribution Fitting Tool.

Most, but not all, of the distributions available in the Distribution Fitting Tool are supported elsewhere in Statistics Toolbox software (see “Supported Distributions” on page 5-3), and have dedicated distribution fitting functions. These functions compute the majority of the fits in the Distribution Fitting Tool, and are referenced in the list below.

Other fits are computed using functions internal to the Distribution Fitting Tool. Distributions that do not have corresponding Statistics Toolbox fitting functions are described in “Additional Distributions Available in the Distribution Fitting Tool” on page 5-49.

Not all of the distributions listed below are available for all data sets. The Distribution Fitting Tool determines the extent of the data (nonnegative, unit interval, etc.) and displays appropriate distributions in the **Distribution** drop-down list. Distribution data ranges are given parenthetically in the list below.

- Beta (unit interval values) distribution, fit using the function `betafit`.
- Binomial (nonnegative values) distribution, fit using the function `binopdf`.
- Birnbaum-Saunders (positive values) distribution.
- Burr Type XII (positive values) distribution.
- Exponential (nonnegative values) distribution, fit using the function `expfit`.

- Extreme value (all values) distribution, fit using the function `evfit`.
- Gamma (positive values) distribution, fit using the function `gamfit`.
- Generalized extreme value (all values) distribution, fit using the function `gevfit`.
- Generalized Pareto (all values) distribution, fit using the function `gpfit`.
- Inverse Gaussian (positive values) distribution.
- Logistic (all values) distribution.
- Loglogistic (positive values) distribution.
- Lognormal (positive values) distribution, fit using the function `lognfit`.
- Nakagami (positive values) distribution.
- Negative binomial (nonnegative values) distribution, fit using the function `nbinpdf`.
- Nonparametric (all values) distribution, fit using the function `ksdensity`. See “Further Options for Nonparametric Fits” on page 5-24 for a description of available options.
- Normal (all values) distribution, fit using the function `normfit`.
- Poisson (nonnegative integer values) distribution, fit using the function `poisspdf`.
- Rayleigh (positive values) distribution using the function `raylfit`.
- Rician (positive values) distribution.
- t location-scale (all values) distribution.
- Weibull (positive values) distribution using the function `wblfit`.

Further Options for Nonparametric Fits. When you select Non-parametric in the **Distribution** field, a set of options appears in the **Non-parametric** pane, as shown in the following figure.

The image shows a dialog box titled "Non-parametric" with the following settings:

- Kernel:** A dropdown menu set to "Normal".
- Bandwidth:** Radio buttons for "Auto" (selected) and "Specify" (with an empty text input field).
- Domain:** Radio buttons for "Unbounded" (selected), "Positive", and "Specify" (with two empty text input fields separated by the word "to").

The options for nonparametric distributions are:

- **Kernel** — Type of kernel function to use.
 - Normal
 - Box
 - Triangle
 - Epanechnikov
- **Bandwidth** — The bandwidth of the kernel smoothing window. Select **Auto** for a default value that is optimal for estimating normal densities. This value appears in the **Fit results** pane after you click **Apply**. Select **Specify** and enter a smaller value to reveal features such as multiple modes or a larger value to make the fit smoother.
- **Domain** — The allowed x -values for the density.
 - **Unbounded** — The density extends over the whole real line.
 - **Positive** — The density is restricted to positive values.
 - **Specify** — Enter lower and upper bounds for the domain of the density.

When you select **Positive** or **Specify**, the nonparametric fit has zero probability outside the specified domain.

Displaying Results

This section explains the different ways to display results in the Distribution Fitting Tool window. This window displays plots of:

- The data sets for which you select **Plot** in the Data dialog box
- The fits for which you select **Plot** in the Fit Manager dialog box
- Confidence bounds for:
 - Data sets for which you select **Bounds** in the Data dialog box
 - Fits for which you select **Bounds** in the Fit Manager dialog box

The following fields are available.

Display Type. The **Display Type** field in the main window specifies the type of plot displayed. Each type corresponds to a probability function, for example, a probability density function. The following display types are available:

- **Density (PDF)** — Display a probability density function (PDF) plot for the fitted distribution. The main window displays data sets using a probability histogram, in which the height of each rectangle is the fraction of data points that lie in the bin divided by the width of the bin. This makes the sum of the areas of the rectangles equal to 1.
- **Cumulative probability (CDF)** — Display a cumulative probability plot of the data. The main window displays data sets using a cumulative probability step function. The height of each step is the cumulative sum of the heights of the rectangles in the probability histogram.
- **Quantile (inverse CDF)** — Display a quantile (inverse CDF) plot.
- **Probability plot** — Display a probability plot of the data. You can specify the type of distribution used to construct the probability plot in the **Distribution** field, which is only available when you select **Probability plot**. The choices for the distribution are:
 - Exponential
 - Extreme value
 - Logistic
 - Log-Logistic

- Lognormal
- Normal
- Rayleigh
- Weibull

In addition to these choices, you can create a probability plot against a parametric fit that you create in the **New Fit** pane. These fits are added at the bottom of the **Distribution** drop-down list when you create them.

- Survivor function — Display survivor function plot of the data.
- Cumulative hazard — Display cumulative hazard plot of the data.

Note Some distributions are unavailable if the plotted data includes 0 or negative values.

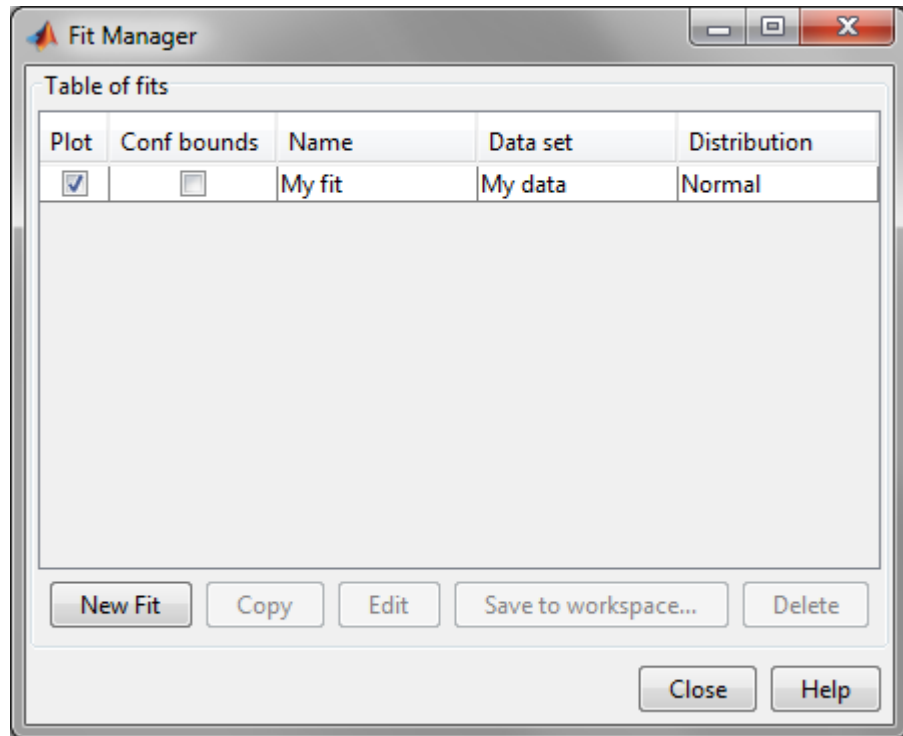
Confidence Bounds. You can display confidence bounds for data sets and fits when you set **Display Type** to Cumulative probability (CDF), Survivor function, Cumulative hazard, or, for fits only, Quantile (inverse CDF).

- To display bounds for a data set, select **Bounds** next to the data set in the **Data sets** pane of the Data dialog box.
- To display bounds for a fit, select **Bounds** next to the fit in the Fit Manager dialog box. Confidence bounds are not available for all fit types.

To set the confidence level for the bounds, select **Confidence Level** from the **View** menu in the main window and choose from the options.

Managing Fits

This section describes how to manage fits that you have created. To begin, click the **Manage Fits** button in the Distribution Fitting Tool. This opens the Fit Manager dialog box as shown in the following figure.



The **Table of fits** displays a list of the fits you create, with the following options:

- **Plot** — Select **Plot** to display a plot of the fit in the main window of the Distribution Fitting Tool. When you create a new fit, **Plot** is selected by default. Clearing the **Plot** check box removes the fit from the plot in the main window.
- **Bounds** — If **Plot** is selected, you can also select **Bounds** to display confidence bounds in the plot. The bounds are displayed when you set **Display Type** in the main window to one of the following:
 - Cumulative probability (CDF)
 - Quantile (inverse CDF)
 - Survivor function

- **Cumulative hazard**

The Distribution Fitting Tool cannot display confidence bounds on density (PDF) or probability plots. In addition, bounds are not supported for nonparametric fits and some parametric fits.

Clearing the **Bounds** check box removes the confidence intervals from the plot in the main window.

When you select a fit in the **Table of fits**, the following buttons are enabled below the table:

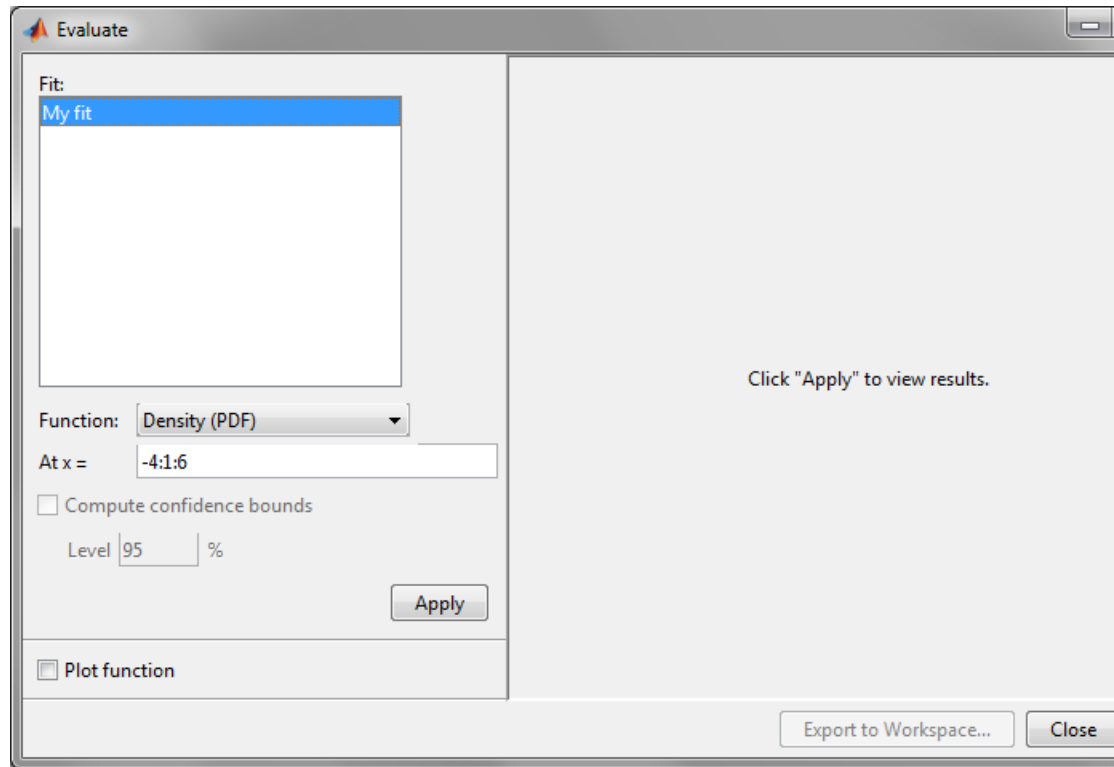
- **New Fit** — Open a New Fit window.
- **Copy** — Create a copy of the selected fit.
- **Edit** — Open an Edit Fit dialog box, where you can edit the fit.

Note You can only edit the currently selected fit in the Edit Fit dialog box. To edit a different fit, select it in the **Table of fits** and click **Edit** to open another Edit Fit dialog box.

- **Save to workspace** — Save the selected fit as a distribution object. See “Using Probability Distribution Objects” on page 5-85 for more information.
- **Delete** — Delete the selected fit.

Evaluating Fits

The Evaluate dialog box enables you to evaluate any fit at whatever points you choose. To open the dialog box, click the **Evaluate** button in the Distribution Fitting Tool. The following figure shows the Evaluate dialog box.



The Evaluate dialog box contains the following items:

- **Fit** pane — Display the names of existing fits. Select one or more fits that you want to evaluate. Using your platform specific functionality, you can select multiple fits.
- **Function** — Select the type of probability function you want to evaluate for the fit. The available functions are
 - Density (PDF) — Computes a probability density function.
 - Cumulative probability (CDF) — Computes a cumulative probability function.
 - Quantile (inverse CDF) — Computes a quantile (inverse CDF) function.

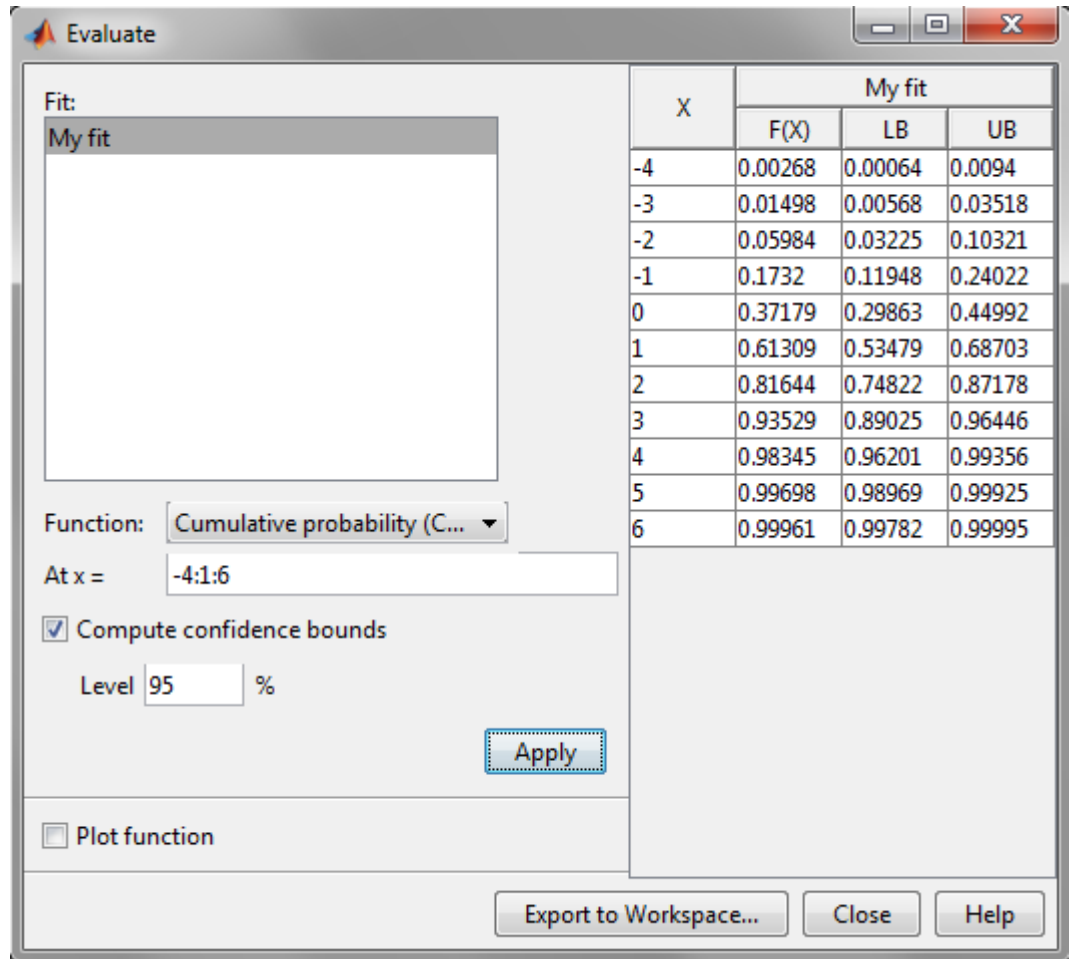
- Survivor function — Computes a survivor function.
- Cumulative hazard — Computes a cumulative hazard function.
- Hazard rate — Computes the hazard rate.
- **At $x =$** — Enter a vector of points or the name of a workspace variable containing a vector of points at which you want to evaluate the distribution function. If you change **Function** to **Quantile (inverse CDF)**, the field name changes to **At $p =$** and you enter a vector of probability values.
- **Compute confidence bounds** — Select this box to compute confidence bounds for the selected fits. The check box is only enabled if you set **Function** to one of the following:
 - Cumulative probability (CDF)
 - Quantile (inverse CDF)
 - Survivor function
 - Cumulative hazard

The Distribution Fitting Tool cannot compute confidence bounds for nonparametric fits and for some parametric fits. In these cases, the tool returns NaN for the bounds.

- **Level** — Set the level for the confidence bounds.
- **Plot function** — Select this box to display a plot of the distribution function, evaluated at the points you enter in the **At $x =$** field, in a new window.

Note The settings for **Compute confidence bounds**, **Level**, and **Plot function** do not affect the plots that are displayed in the main window of the Distribution Fitting Tool. The settings only apply to plots you create by clicking **Plot function** in the Evaluate window.

Click **Apply** to apply these settings to the selected fit. The following figure shows the results of evaluating the cumulative density function for the fit **My fit**, created in “Example: Fitting a Distribution” on page 5-40, at the points in the vector `-4:1:6`.



The window displays the following values in the columns of the table to the right of the **Fit** pane:

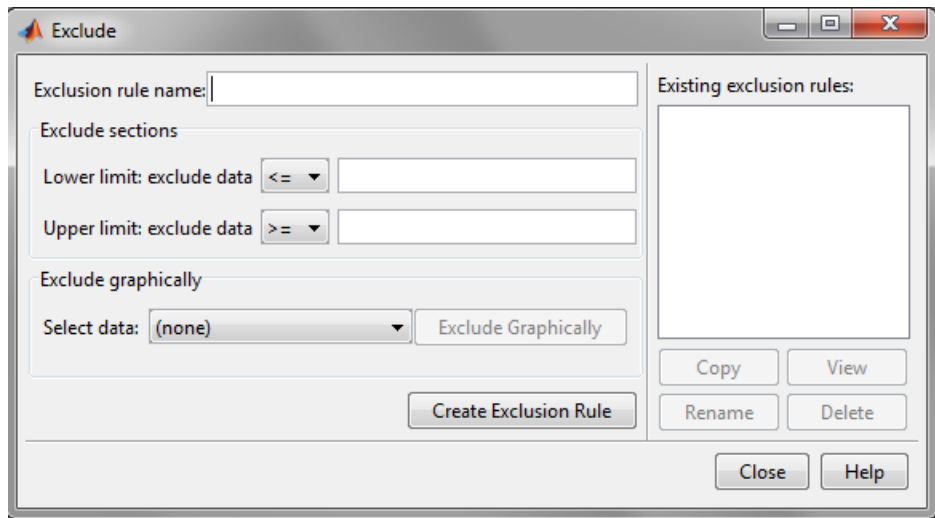
- X — The entries of the vector you enter in **At x =** field
- F(X)— The corresponding values of the CDF at the entries of X
- LB — The lower bounds for the confidence interval, if you select **Compute confidence bounds**

- UB — The upper bounds for the confidence interval, if you select **Compute confidence bounds**

To save the data displayed in the Evaluate window, click **Export to Workspace**. This saves the values in the table to a matrix in the MATLAB workspace.

Excluding Data

To exclude values from fit, click the **Exclude** button in the main window of the Distribution Fitting Tool. This opens the Exclude window, in which you can create rules for excluding specified values. You can use these rules to exclude data when you create a new fit in the New Fit window. The following figure shows the Exclude window.



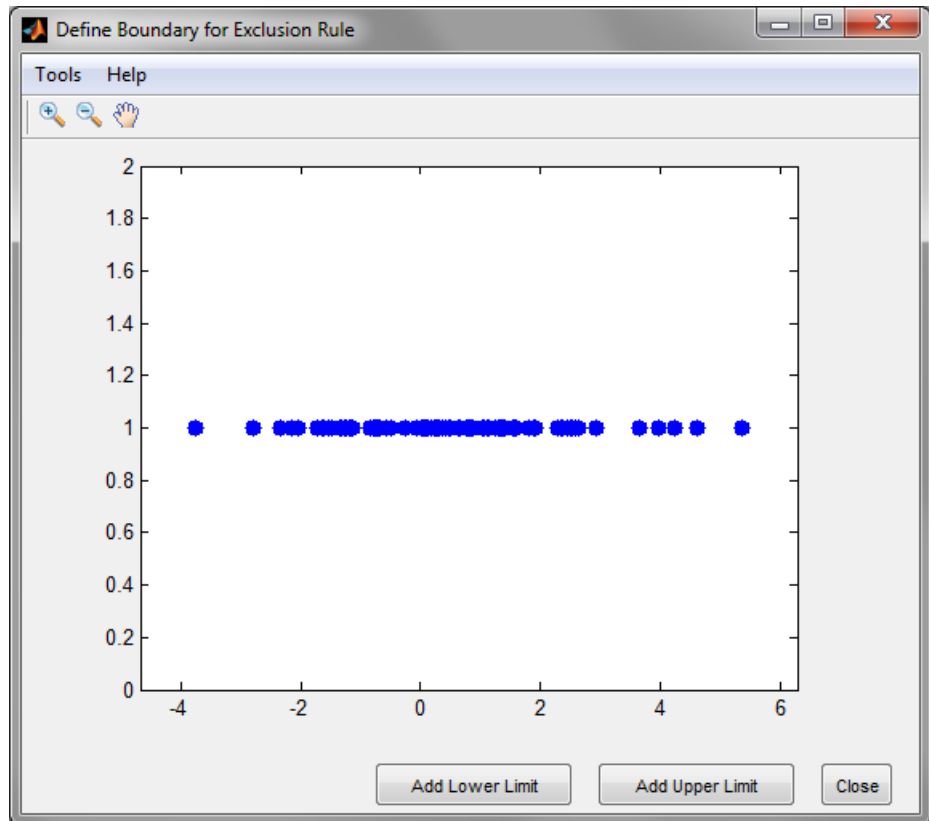
To create an exclusion rule:

- 1 Exclusion Rule Name**—Enter a name for the exclusion rule in the **Exclusion rule name** field.
- 2 Exclude Sections**—In the **Exclude sections** pane, you can specify bounds for the excluded data:

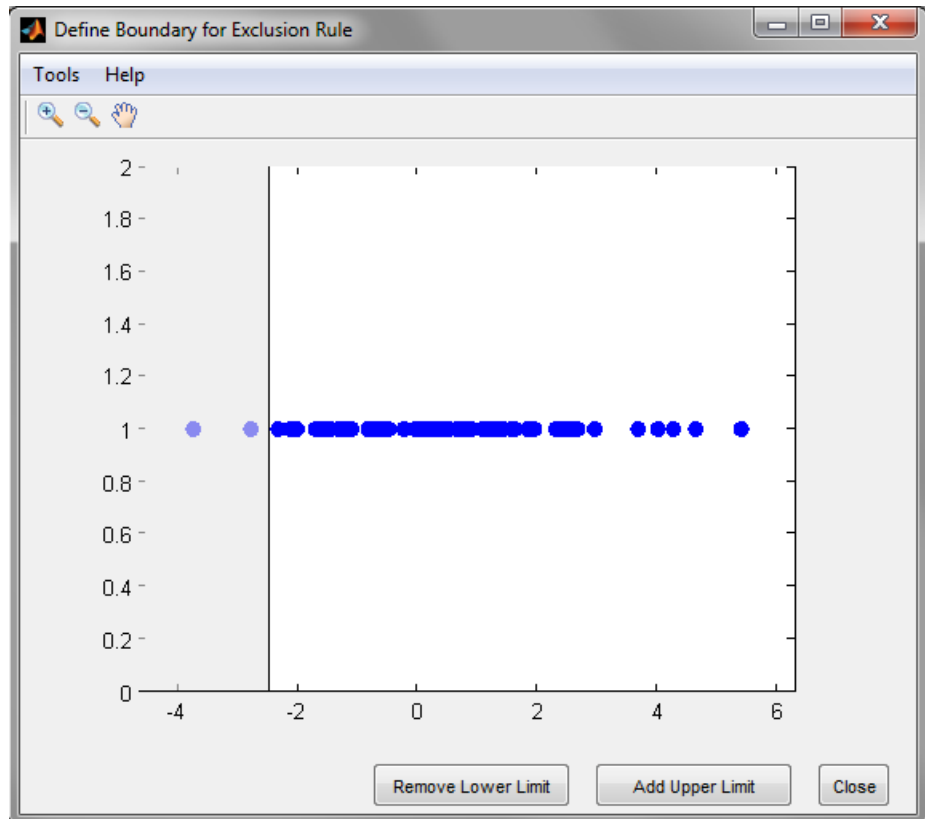
- In the **Lower limit: exclude Y** drop-down list, select \leq or $<$ from the drop-down list and enter a scalar in the field to the right. This excludes values that are either less than or equal to or less than that scalar, respectively.
- In the **Upper limit: exclude Y** drop-down list, select \geq or $>$ from the drop-down list and enter a scalar in the field to the right to exclude values that are either greater than or equal to or greater than the scalar, respectively.

OR

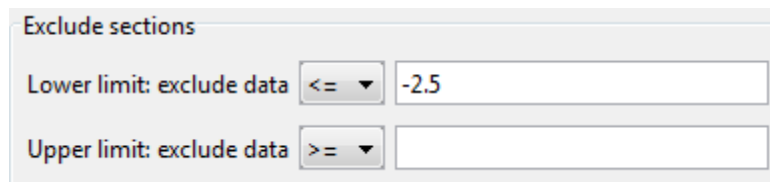
Exclude Graphically—The **Exclude Graphically** button enables you to define the exclusion rule by displaying a plot of the values in a data set and selecting the bounds for the excluded data with the mouse. For example, if you created the data set *My data*, described in “Creating and Managing Data Sets” on page 5-15, select it from the drop-down list next to **Exclude graphically** and then click the **Exclude graphically** button. This displays the values in *My data* in a new window as shown in the following figure.



To set a lower limit for the boundary of the excluded region, click **Add Lower Limit**. This displays a vertical line on the left side of the plot window. Move the line with the mouse to the point you where you want the lower limit, as shown in the following figure.



Moving the vertical line changes the value displayed in the **Lower limit: exclude data** field in the Exclude window, as shown in the following figure.



The value displayed corresponds to the x -coordinate of the vertical line.

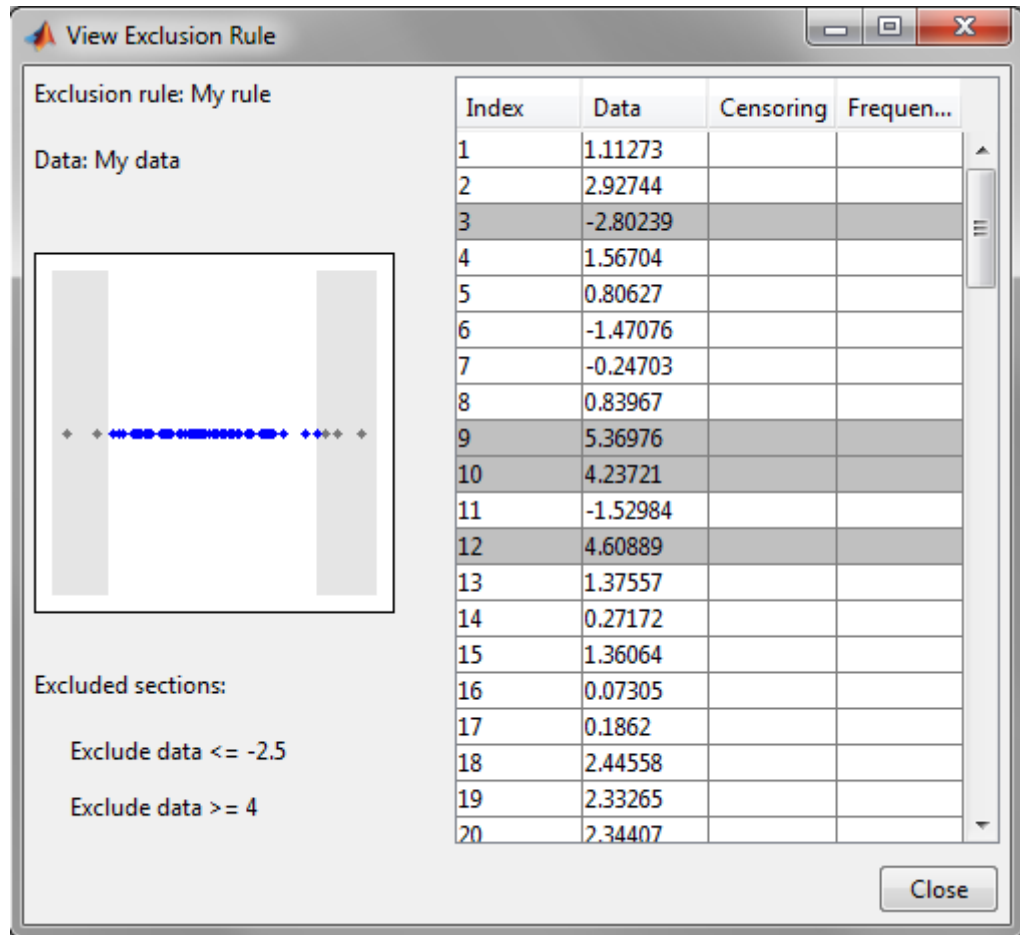
Similarly, you can set the upper limit for the boundary of the excluded region by clicking **Add Upper Limit** and moving the vertical line that

appears at the right side of the plot window. After setting the lower and upper limits, click **Close** and return to the Exclude window.

- 3 Create Exclusion Rule**—Once you have set the lower and upper limits for the boundary of the excluded data, click **Create Exclusion Rule** to create the new rule. The name of the new rule now appears in the **Existing exclusion rules** pane.

When you select an exclusion rule in the **Existing exclusion rules** pane, the following buttons are enabled:

- **Copy** — Creates a copy of the rule, which you can then modify. To save the modified rule under a different name, click **Create Exclusion Rule**.
- **View** — Opens a new window in which you can see which data points are excluded by the rule. The following figure shows a typical example.



The shaded areas in the plot graphically display which data points are excluded. The table to the right lists all data points. The shaded rows indicate excluded points:

- **Rename** — Renames the rule
- **Delete** — Deletes the rule

Once you define an exclusion rule, you can use it when you fit a distribution to your data. The rule does not exclude points from the display of the data set.

Saving and Loading Sessions

This section explains how to save your work in the current Distribution Fitting Tool session and then load it in a subsequent session, so that you can continue working where you left off.

Saving a Session. To save the current session, select **Save Session** from the **File** menu in the main window. This opens a dialog box that prompts you to enter a filename, such as `my_session.dfit`, for the session. Clicking **Save** saves the following items created in the current session:

- Data sets
- Fits
- Exclusion rules
- Plot settings
- Bin width rules

Loading a Session. To load a previously saved session, select **Load Session** from the **File** menu in the main window and enter the name of a previously saved session. Clicking **Open** restores the information from the saved session to the current session of the Distribution Fitting Tool.

Example: Fitting a Distribution

This section presents an example that illustrates how to use the Distribution Fitting Tool. The example involves the following steps:

- “Step 1: Generate Random Data” on page 5-40
- “Step 2: Import Data” on page 5-40
- “Step 3: Create a New Fit” on page 5-43

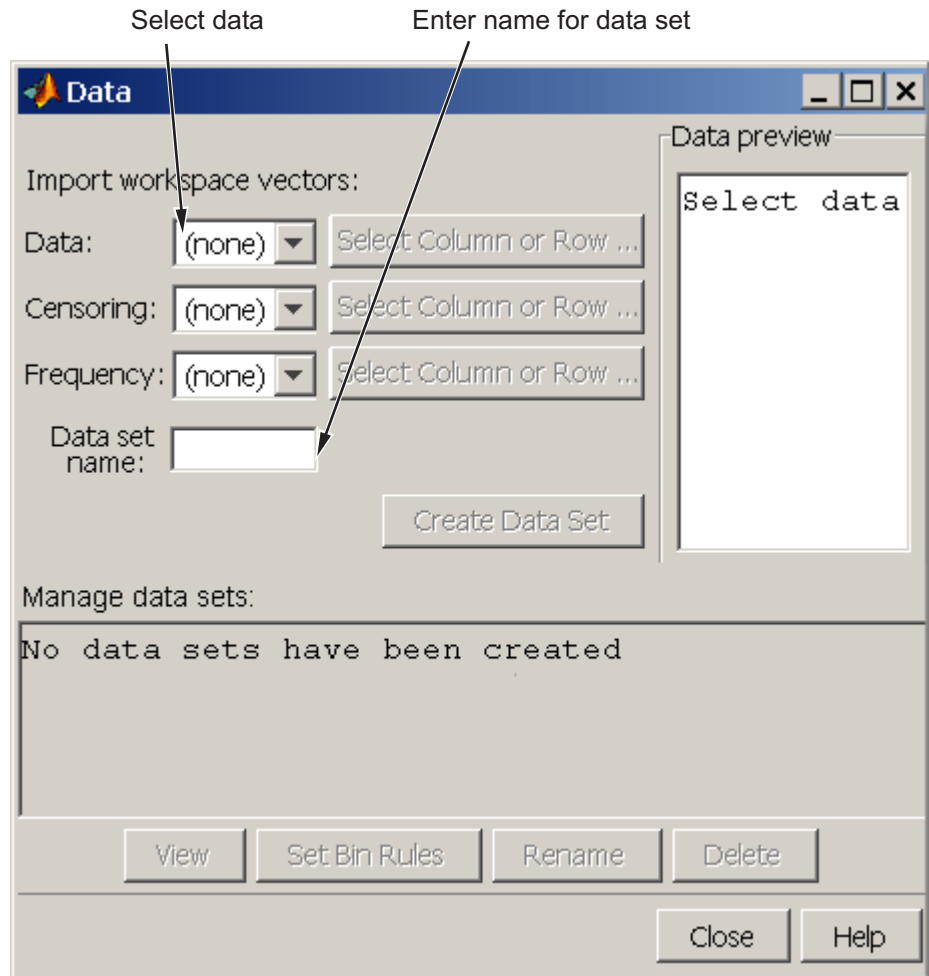
Step 1: Generate Random Data. To try the example, first generate some random data to which you will fit a distribution. The following command generates a vector `data`, of length 100, whose entries are random numbers from a normal distribution with mean .36 and standard deviation 1.4.

```
rng('default')
data = normrnd(.36, 1.4, 100, 1);
```

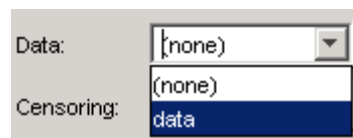
Step 2: Import Data. Open the distribution fitting tool:

```
dffittool
```

To import the vector `data` into the Distribution Fitting Tool, click the **Data** button in main window. This opens the window shown in the following figure.

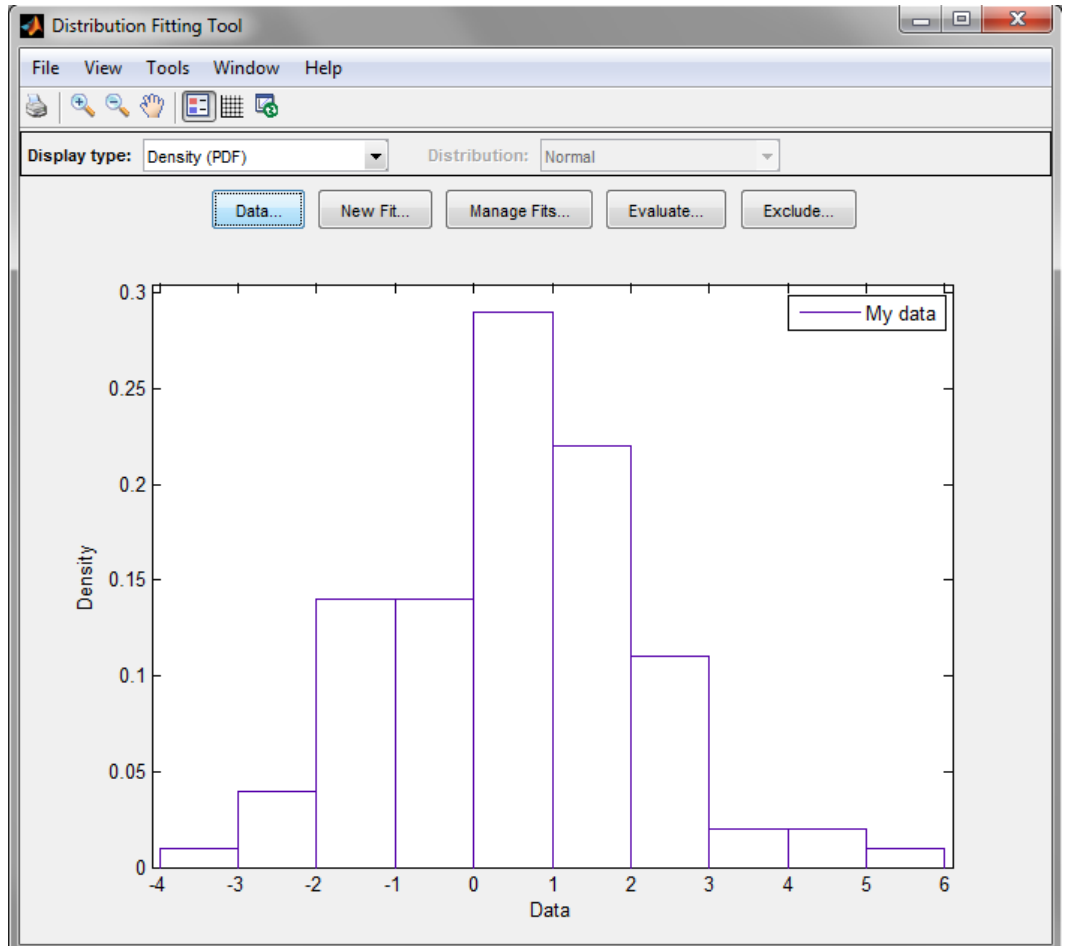


The **Data** field displays all numeric arrays in the MATLAB workspace. Select data from the drop-down list, as shown in the following figure.



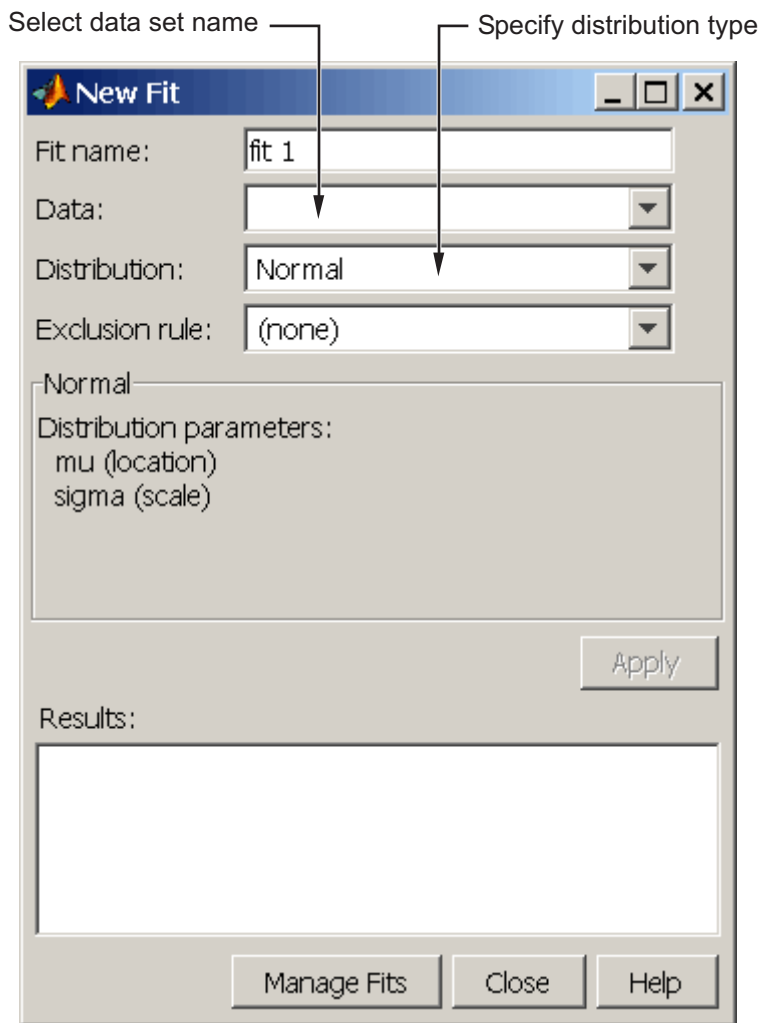
This displays a histogram of the data in the **Data preview** pane.

In the **Data set name** field, type a name for the data set, such as **My data**, and click **Create Data Set** to create the data set. The main window of the Distribution Fitting Tool now displays a larger version of the histogram in the **Data preview** pane, as shown in the following figure.



Note Because the example uses random data, you might see a slightly different histogram if you try this example for yourself.

Step 3: Create a New Fit. To fit a distribution to the data, click **New Fit** in the main window of the Distribution Fitting Tool. This opens the window shown in the following figure.

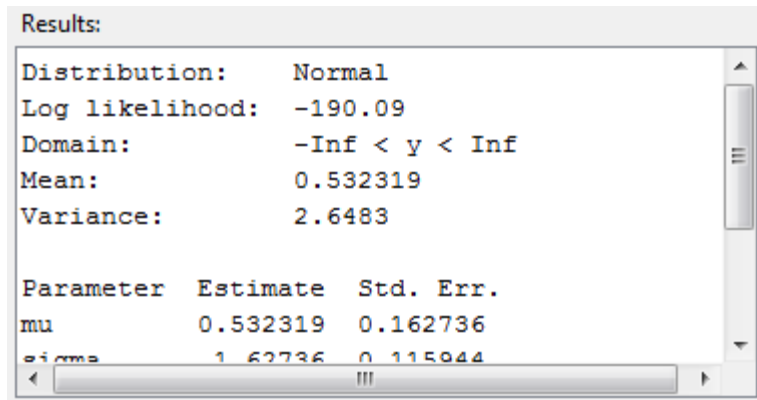


To fit a normal distribution, the default entry of the **Distribution** field, to My data:

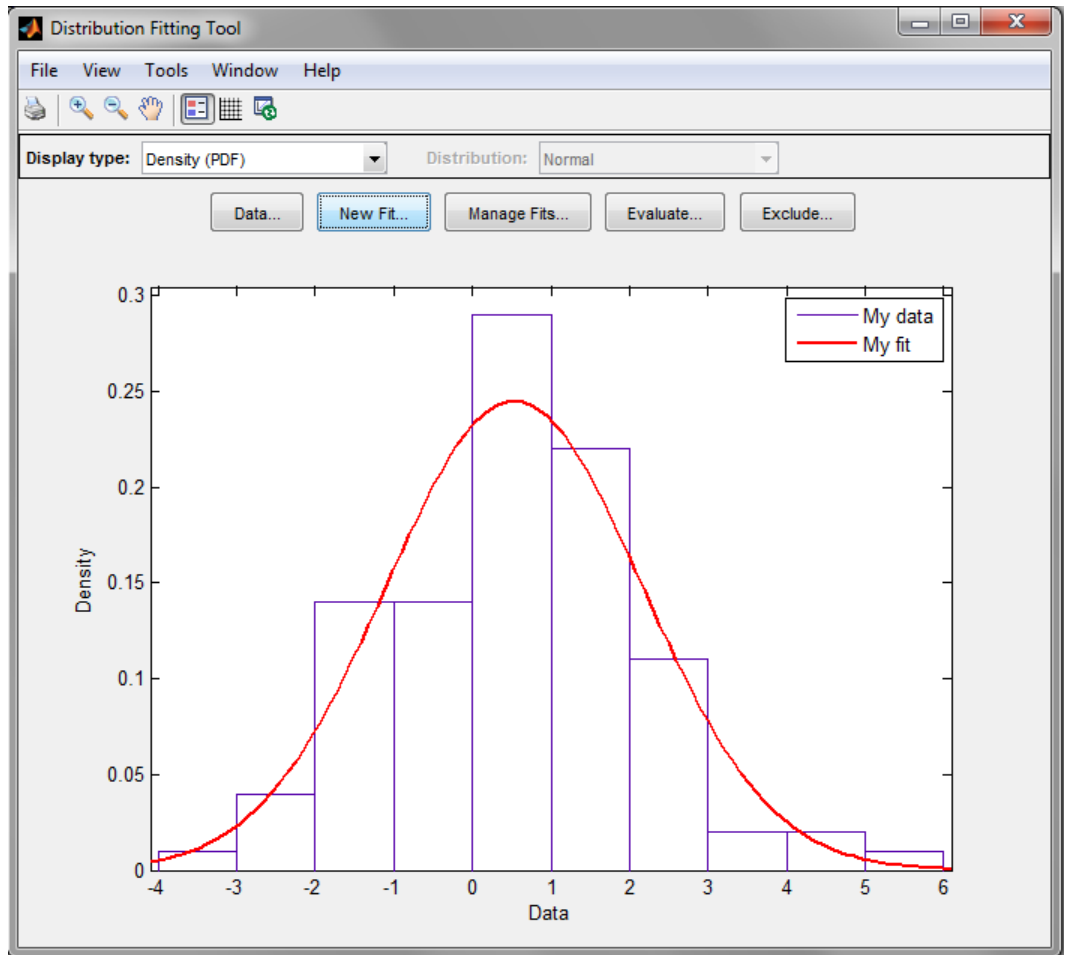
- 1 Enter a name for the fit, such as My fit, in the **Fit name** field.
- 2 Select My data from the drop-down list in the **Data** field.

3 Click **Apply**.

The **Results** pane displays the mean and standard deviation of the normal distribution that best fits My data, as shown in the following figure.



The main window of the Distribution Fitting Tool displays a plot of the normal distribution with this mean and standard deviation, as shown in the following figure.



Generating a File to Fit and Plot Distributions

The **Generate Code** option in the **File** menu enables you to create a file that

- Fits the distributions used in the current session to any data vector in the MATLAB workspace.
- Plots the data and the fits.

After you end the current session, you can use the file to create plots in a standard MATLAB figure window, without having to reopen the Distribution Fitting Tool.

As an example, assuming you created the fit described in “Creating a New Fit” on page 5-20, do the following steps:

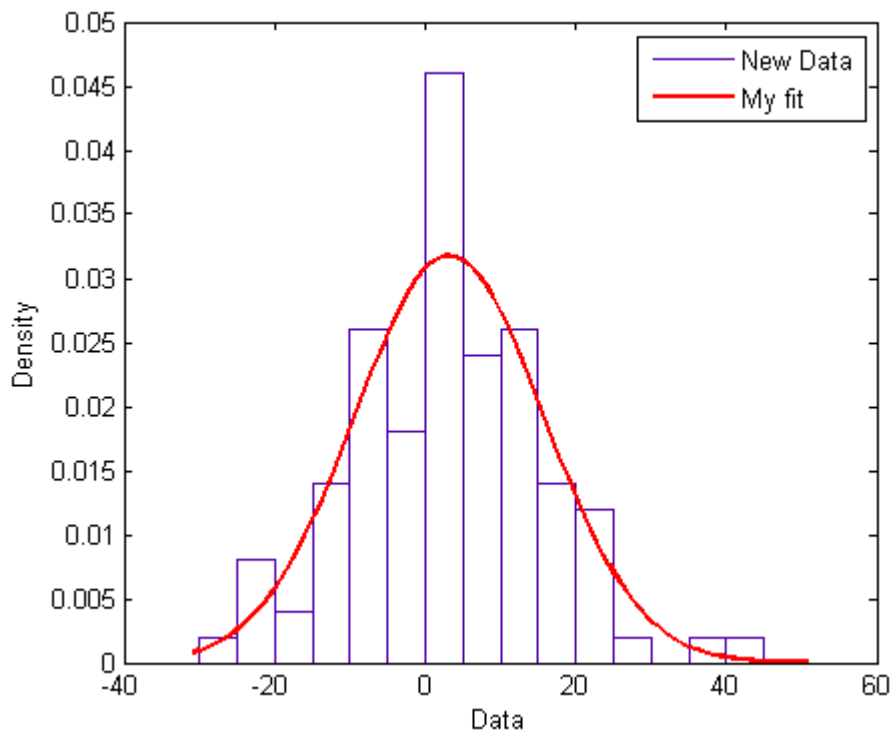
- 1** Select **Generate Code** from the **File** menu.
- 2** Choose **File > Save as** in the MATLAB Editor window. Save the file as `normal_fit.m` in a folder on the MATLAB path.

You can then apply the function `normal_fit` to any vector of data in the MATLAB workspace. For example, the following commands

```
new_data = normrnd(4.1, 12.5, 100, 1);
newfit = normal_fit(new_data)
legend('New Data', 'My fit')
```

generate `newfit`, a fitted normal distribution of the data, and generates a plot of the data and the fit.

```
newfit =
normal distribution
    mu = 3.19148
    sigma = 12.5631
```



Note By default, the file labels the data in the legend using the same name as the data set in the Distribution Fitting Tool. You can change the label using the `legend` command, as illustrated by the preceding example.

Additional Distributions Available in the Distribution Fitting Tool

The following distributions are available in the Distribution Fitting Tool, but do not have dedicated distribution functions as described in “Statistics Toolbox Distribution Functions” on page 5-53. The distributions can be used with the functions `pdf`, `cdf`, `icdf`, and `mle` in a limited capacity. See the reference pages for these functions for details on the limitations.

- “Birnbaum-Saunders Distribution” on page B-10
- “Burr Type XII Distribution” on page B-12
- “Inverse Gaussian Distribution” on page B-58
- “Loglogistic Distribution” on page B-63
- “Logistic Distribution” on page B-62
- “Nakagami Distribution” on page B-83
- “Rician Distribution” on page B-106
- “t Location-Scale Distribution” on page B-110

For a complete list of the distributions available for use with the Distribution Fitting Tool, see “Supported Distributions” on page 5-3. Distributions listing `dfittool` in the **fit** column of the tables in that section can be used with the Distribution Fitting Tool.

Custom Distributions Using Distribution Fitting Tool

This section explains how to use custom distributions with the Distribution Fitting Tool.

Defining Custom Distributions

To define a custom distribution, select `Define Custom Distribution` from the **File** menu. This opens a file template in the MATLAB editor. You then edit this file so that it computes the distribution you want.

The template includes example code that computes the Laplace distribution, beginning at the lines

```
%  
% Remove the following return statement to define the  
% Laplace distributon  
%  
return
```

To use this example, simply delete the command `return` and save the file. If you save the template in a folder on the MATLAB path, under its default name `dfittooldists.m`, the Distribution Fitting Tool reads it in automatically when you start the tool. You can also save the template under a different name, such as `laplace.m`, and then import the custom distribution as described in the following section.

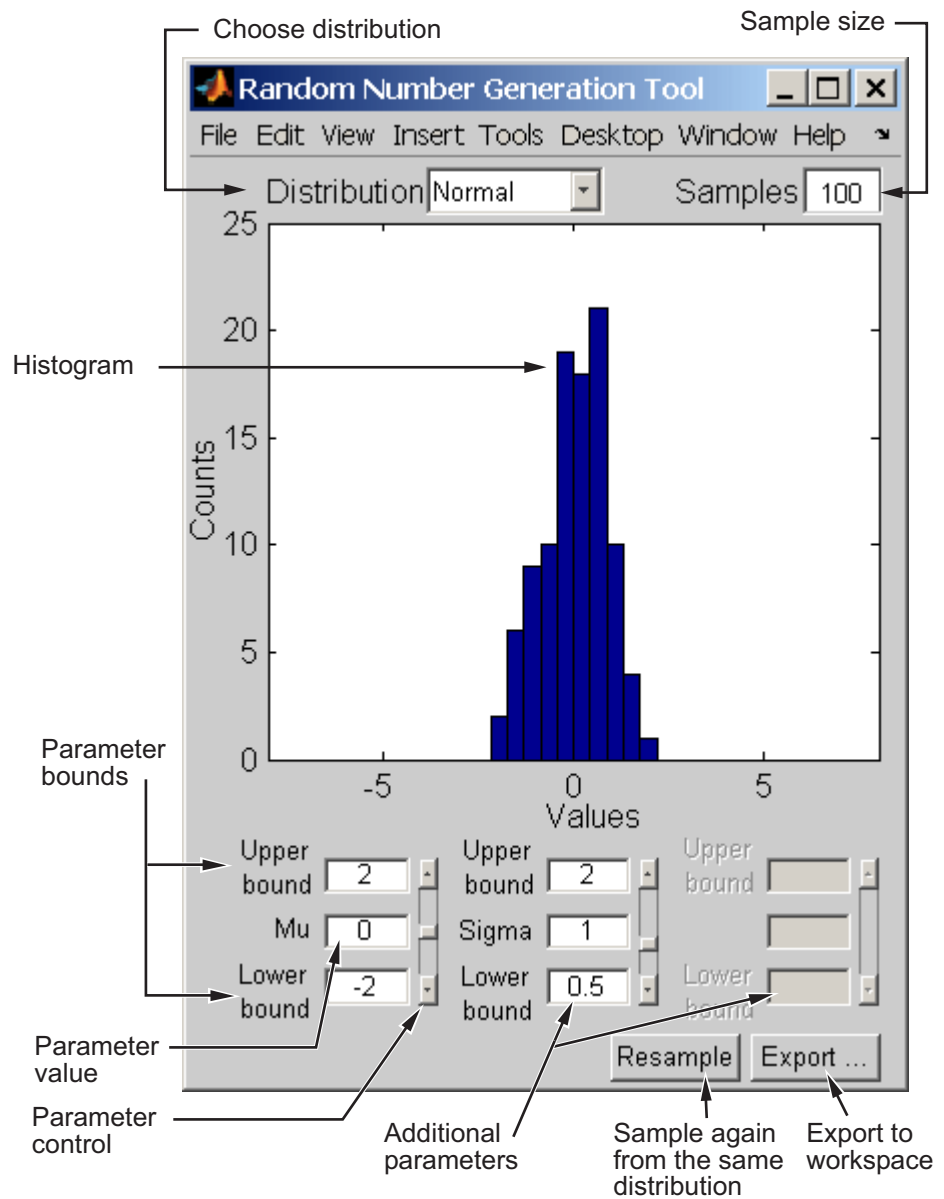
Importing Custom Distributions

To import a custom distribution, select **Import Custom Distributions** from the **File** menu. This opens a dialog box in which you can select the file that defines the distribution. For example, if you created the file `laplace.m`, as described in the preceding section, you can enter `laplace.m` and select **Open** in the dialog box. The **Distribution** field of the New Fit window now contains the option `Laplace`.

Visually Exploring Random Number Generation

The Random Number Generation Tool is a graphical user interface that generates random samples from specified probability distributions and displays the samples as histograms. Use the tool to explore the effects of changing parameters and sample size on the distributions.

Run the tool by typing `randtool` at the command line.



Start by selecting a distribution, then enter the desired sample size.

You can also

- Use the controls at the bottom of the window to set parameter values for the distribution and to change their upper and lower bounds.
- Draw another sample from the same distribution, with the same size and parameters.
- Export the current sample to your workspace. A dialog box enables you to provide a name for the sample.

Statistics Toolbox Distribution Functions

In this section...

“Probability Density Functions” on page 5-53

“Cumulative Distribution Functions” on page 5-63

“Inverse Cumulative Distribution Functions” on page 5-67

“Distribution Statistics Functions” on page 5-69

“Distribution Fitting Functions” on page 5-71

“Negative Log-Likelihood Functions” on page 5-78

“Random Number Generators” on page 5-81

For each distribution supported by Statistics Toolbox software, a selection of the distribution functions described in this section is available for statistical programming. This section gives a general overview of the use of each type of function, independent of the particular distribution. For specific functions available for specific distributions, see “Supported Distributions” on page 5-3.

Probability Density Functions

- “Estimating PDFs with Parameters” on page 5-53
- “Estimating PDFs without Parameters” on page 5-56

Estimating PDFs with Parameters

Probability density functions (pdfs) for supported Statistics Toolbox distributions all end with `pdf`, as in `binopdf` or `expdf`. For more information on specific function names for specific distributions see “Supported Distributions” on page 5-3.

Each function represents a parametric family of distributions. Input arguments are arrays of outcomes followed by a list of parameter values specifying a particular member of the distribution family.

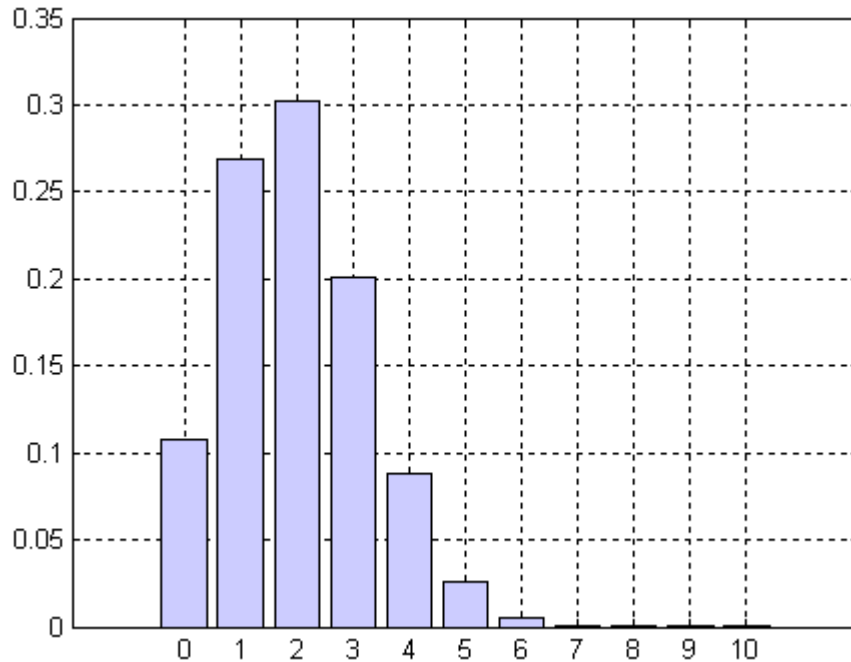
For discrete distributions, the pdf assigns a probability to each outcome. In this context, the pdf is often called a *probability mass function (pmf)*.

For example, the discrete binomial pdf

$$f(k) = \binom{n}{k} p^k (1-p)^{n-k}$$

assigns probability to the event of k successes in n trials of a Bernoulli process (such as coin flipping) with probability p of success at each trial. Each of the integers $k = 0, 1, 2, \dots, n$ is assigned a positive probability, with the sum of the probabilities equal to 1. Compute the probabilities with the `binopdf` function:

```
p = 0.2; % Probability of success for each trial
n = 10; % Number of trials
k = 0:n; % Outcomes
m = binopdf(k,n,p); % Probability mass vector
bar(k,m) % Visualize the probability distribution
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
grid on
```



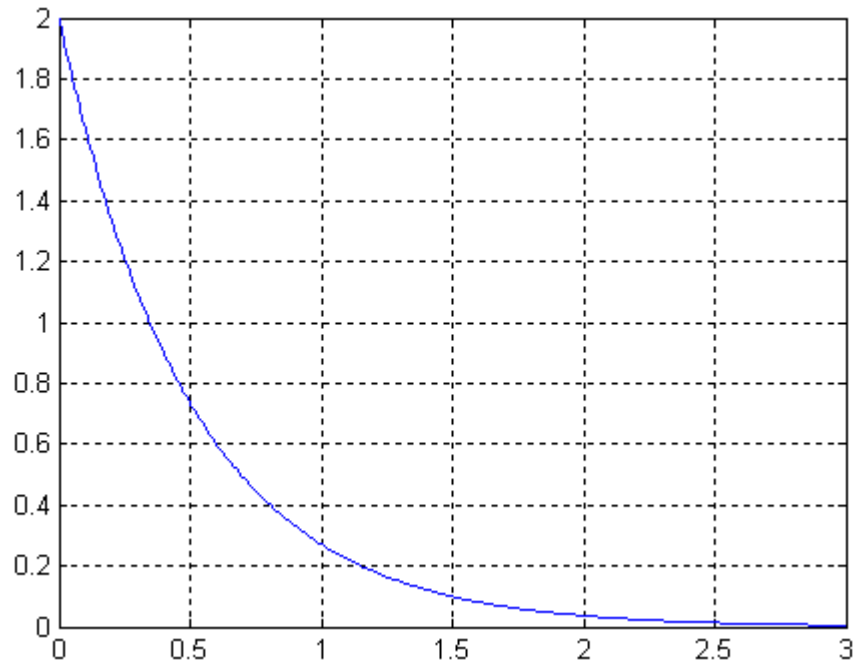
For continuous distributions, the pdf assigns a probability *density* to each outcome. The probability of any single outcome is zero. The pdf must be integrated over a set of outcomes to compute the probability that an outcome falls within that set. The integral over the entire set of outcomes is 1.

For example, the continuous exponential pdf

$$f(t) = \lambda e^{-\lambda t}$$

is used to model the probability that a process with constant failure rate λ will have a failure within time t . Each time $t > 0$ is assigned a positive probability density. Densities are computed with the `exppdf` function:

```
lambda = 2; % Failure rate
t = 0:0.01:3; % Outcomes
f = exppdf(t,1/lambda); % Probability density vector
plot(t,f) % Visualize the probability distribution
grid on
```



Probabilities for continuous pdfs can be computed with the `quad` function. In the example above, the probability of failure in the time interval $[0,1]$ is computed as follows:

```
f_lambda = @(t)exppdf(t,1/lambda); % Pdf with fixed lambda
P = quad(f_lambda,0,1) % Integrate from 0 to 1
P =
    0.8647
```

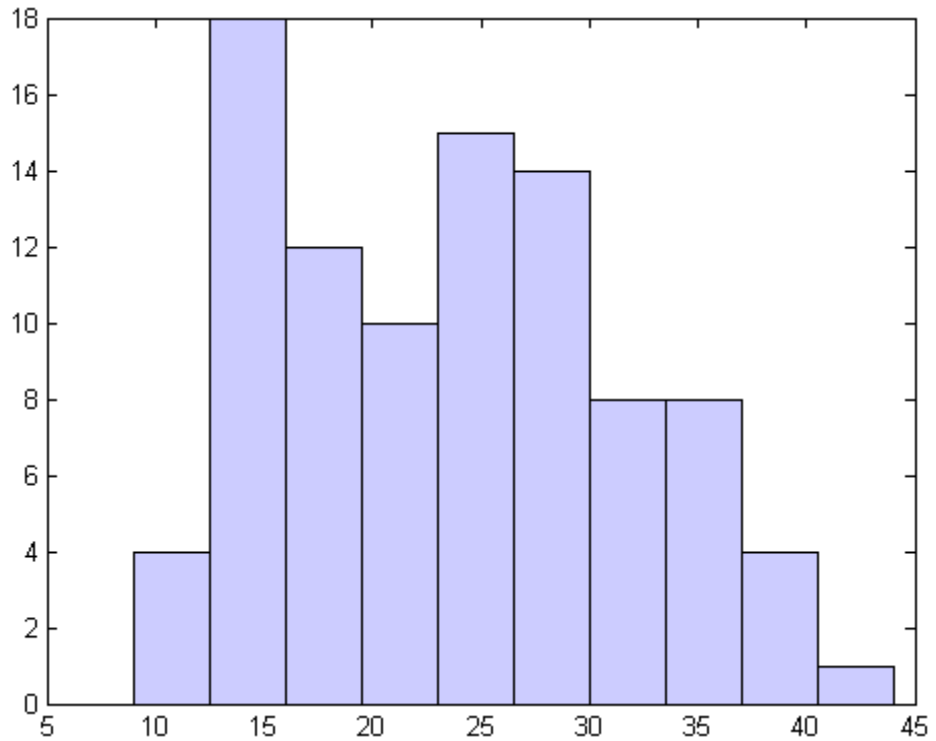
Alternatively, the cumulative distribution function (cdf) for the exponential function, `expcdf`, can be used:

```
P = expcdf(1,1/lambda) % Cumulative probability from 0 to 1
P =
    0.8647
```

Estimating PDFs without Parameters

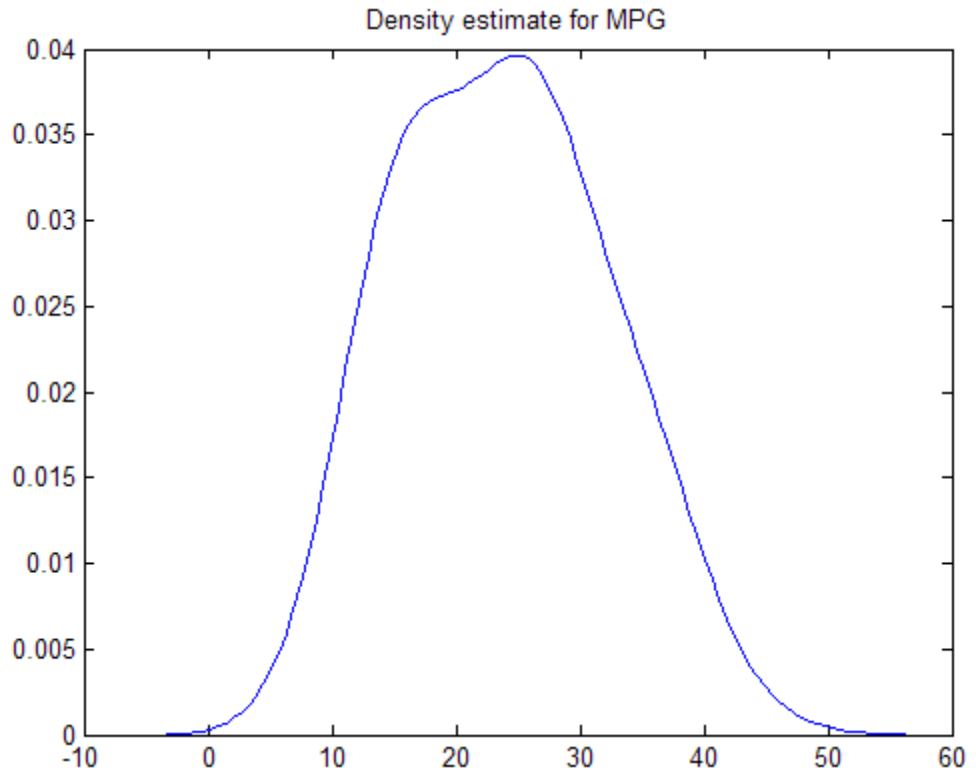
A distribution of data can be described graphically with a histogram:

```
cars = load('carsmall','MPG','Origin');
MPG = cars.MPG;
hist(MPG)
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
```

You can also describe a data distribution by estimating its density. The `ksdensity` function does this using a kernel smoothing method. A nonparametric density estimate of the previous data, using the default kernel and bandwidth, is given by:

```
[f,x] = ksdensity(MPG);  
plot(x,f);  
title('Density estimate for MPG')
```

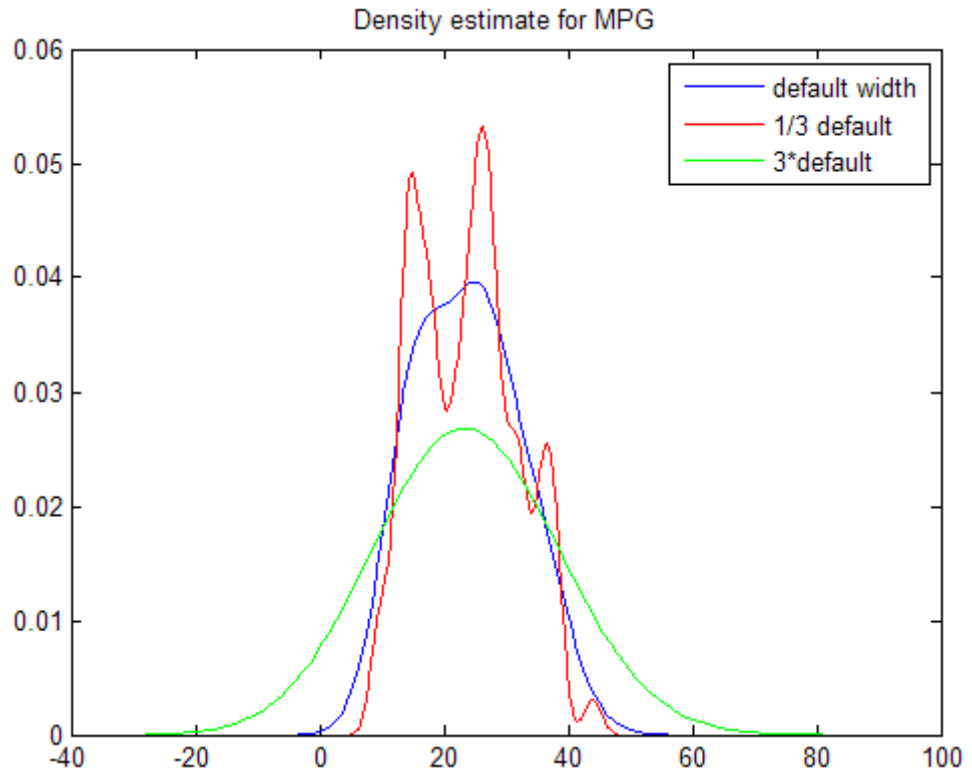


Controlling Probability Density Curve Smoothness. The choice of kernel bandwidth controls the smoothness of the probability density curve. The following graph shows the density estimate for the same mileage data using different bandwidths. The default bandwidth is in blue and looks like the preceding graph. Estimates for smaller and larger bandwidths are in red and green.

The first call to `ksdensity` returns the default bandwidth, `u`, of the kernel smoothing function. Subsequent calls modify this bandwidth.

```
[f,x,u] = ksdensity(MPG);  
plot(x,f)  
title('Density estimate for MPG')  
hold on
```

```
[f,x] = ksdensity(MPG,'width',u/3);  
plot(x,f,'r');  
  
[f,x] = ksdensity(MPG,'width',u*3);  
plot(x,f,'g');  
  
legend('default width','1/3 default','3*default')  
hold off
```



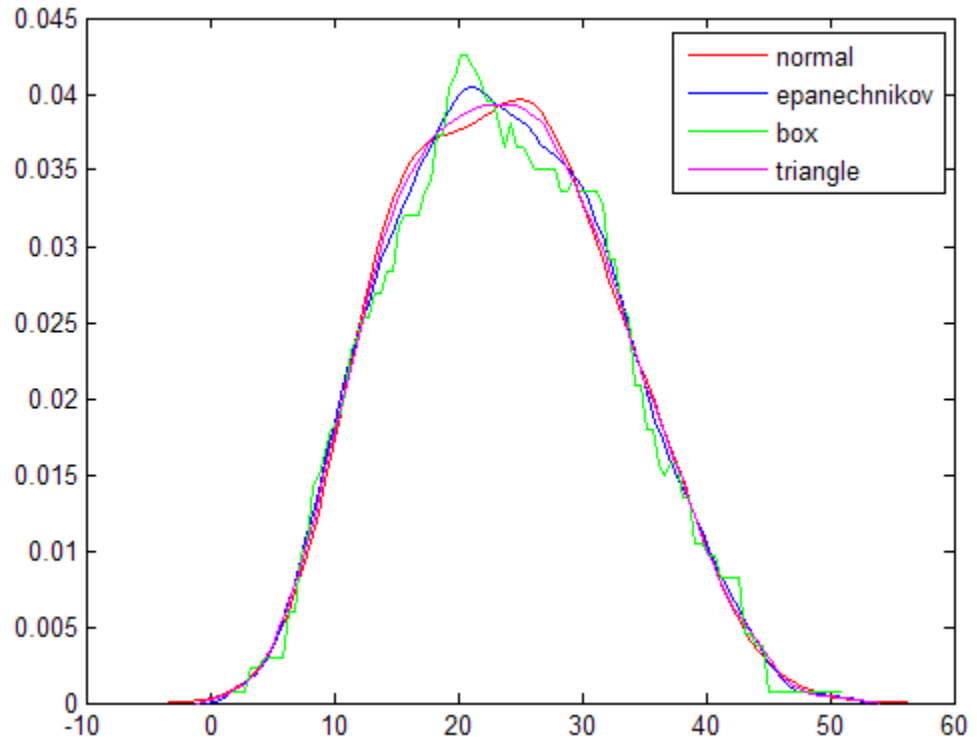
The default bandwidth seems to be doing a good job—reasonably smooth, but not so smooth as to obscure features of the data. This bandwidth is the one that is theoretically optimal for estimating densities for the normal distribution.

The green curve shows a density with the kernel bandwidth set too high. This curve smooths out the data so much that the end result looks just like the kernel function. The red curve has a smaller bandwidth and is rougher looking than the blue curve. It may be too rough, but it does provide an indication that there might be two major peaks rather than the single peak of the blue curve. A reasonable choice of width might lead to a curve that is intermediate between the red and blue curves.

Specifying Kernel Smoothing Functions. You can also specify a kernel function by supplying either the function name or a function handle. The four preselected functions, 'normal', 'epanechnikov', 'box', and 'triangle', are all scaled to have standard deviation equal to 1, so they perform a comparable degree of smoothing.

Using default bandwidths, you can now plot the same mileage data, using each of the available kernel functions.

```
hname = {'normal' 'epanechnikov' 'box' 'triangle'};
colors = {'r' 'b' 'g' 'm'};
for j=1:4
    [f,x] = ksdensity(MPG,'kernel',hname{j});
    plot(x,f,colors{j});
    hold on;
end
legend(hname{:});
hold off
```



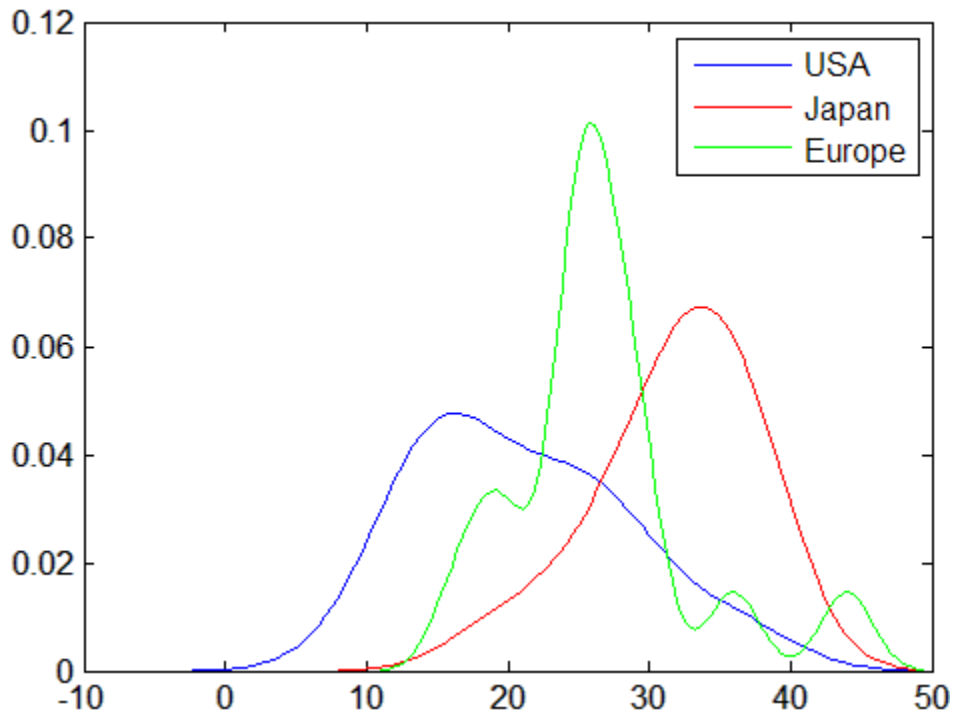
The density estimates are roughly comparable, but the box kernel produces a density that is rougher than the others.

Comparing Density Estimates. While it is difficult to overlay two histograms to compare them, you can easily overlay smooth density estimates. For example, the following graph shows the MPG distributions for cars from different countries of origin:

```
Origin = cellstr(cars.Origin);

I = strcmp('USA',Origin);
J = strcmp('Japan',Origin);
K = ~(I|J);
MPG_USA = MPG(I);
MPG_Japan = MPG(J);
MPG_Europe = MPG(K);
```

```
[fI,xI] = ksdensity(MPG_USA);  
plot(xI,fI,'b')  
hold on  
  
[fJ,xJ] = ksdensity(MPG_Japan);  
plot(xJ,fJ,'r')  
  
[fK,xK] = ksdensity(MPG_Europe);  
plot(xK,fK,'g')  
  
legend('USA','Japan','Europe')  
hold off
```



For piecewise probability density estimation, using kernel smoothing in the center of the distribution and Pareto distributions in the tails, see “Fitting Piecewise Distributions” on page 5-73.

Cumulative Distribution Functions

- “Estimating Parametric CDFs” on page 5-63
- “Estimating Empirical CDFs” on page 5-64

Estimating Parametric CDFs

Cumulative distribution functions (cdf) for supported Statistics Toolbox distributions all end with `cdf`, as in `binocdf` or `expcdf`. Specific function names for specific distributions can be found in “Supported Distributions” on page 5-3.

Each function represents a parametric family of distributions. Input arguments are arrays of outcomes followed by a list of parameter values specifying a particular member of the distribution family.

For discrete distributions, the cdf F is related to the pdf f by

$$F(x) = \sum_{y \leq x} f(y)$$

For continuous distributions, the cdf F is related to the pdf f by

$$F(x) = \int_{-\infty}^x f(y) dy$$

Cdfs are used to compute probabilities of events. In particular, if F is a cdf and x and y are outcomes, then

- $P(y \leq x) = F(x)$
- $P(y > x) = 1 - F(x)$
- $P(x_1 < y \leq x_2) = F(x_2) - F(x_1)$

For example, the t -statistic

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}}$$

follows a Student's t distribution with $n - 1$ degrees of freedom when computed from repeated random samples from a normal population with mean μ . Here \bar{x} is the sample mean, s is the sample standard deviation, and n is the sample size. The probability of observing a t -statistic greater than or equal to the value computed from a sample can be found with the `tcdf` function:

```
mu = 1; % Population mean
sigma = 2; % Population standard deviation
n = 100; % Sample size
x = normrnd(mu,sigma,n,1); % Random sample from population
xbar = mean(x); % Sample mean
s = std(x); % Sample standard deviation
t = (xbar-mu)/(s/sqrt(n)) % t-statistic
t =
    0.2489
p = 1-tcdf(t,n-1) % Probability of larger t-statistic
p =
    0.4020
```

This probability is the same as the p value returned by a t -test of the null hypothesis that the sample comes from a normal population with mean μ :

```
[h,ptest] = ttest(x,mu,0.05,'right')
h =
    0
ptest =
    0.4020
```

Estimating Empirical CDFs

The `ksdensity` function produces an empirical version of a probability density function (pdf). That is, instead of selecting a density with a particular parametric form and estimating the parameters, it produces a nonparametric density estimate that adapts itself to the data.

Similarly, it is possible to produce an empirical version of the cumulative distribution function (cdf). The `ecdf` function computes this empirical cdf. It

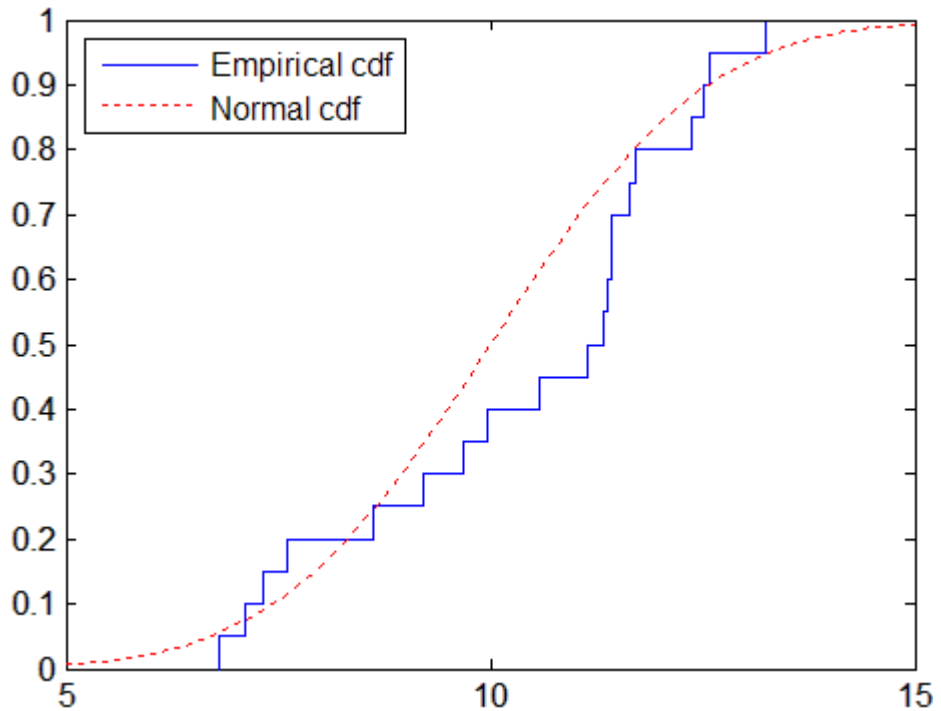
returns the values of a function F such that $F(x)$ represents the proportion of observations in a sample less than or equal to x .

The idea behind the empirical cdf is simple. It is a function that assigns probability $1/n$ to each of n observations in a sample. Its graph has a stair-step appearance. If a sample comes from a distribution in a parametric family (such as a normal distribution), its empirical cdf is likely to resemble the parametric distribution. If not, its empirical distribution still gives an estimate of the cdf for the distribution that generated the data.

The following example generates 20 observations from a normal distribution with mean 10 and standard deviation 2. You can use `ecdf` to calculate the empirical cdf and `stairs` to plot it. Then you overlay the normal distribution curve on the empirical function.

```
x = normrnd(10,2,20,1);
[f,xf] = ecdf(x);

stairs(xf,f)
hold on
xx=linspace(5,15,100);
yy = normcdf(xx,10,2);
plot(xx,yy,'r:')
hold off
legend('Empirical cdf','Normal cdf',2)
```



The empirical cdf is especially useful in survival analysis applications. In such applications the data may be censored, that is, not observed exactly. Some individuals may fail during a study, and you can observe their failure time exactly. Other individuals may drop out of the study, or may not fail until after the study is complete. The `ecdf` function has arguments for dealing with censored data. In addition, you can use the `coxphfit` function with individuals that have predictors that are not the same.

For piecewise probability density estimation, using the empirical cdf in the center of the distribution and Pareto distributions in the tails, see “Fitting Piecewise Distributions” on page 5-73.

Inverse Cumulative Distribution Functions

Inverse cumulative distribution functions for supported Statistics Toolbox distributions all end with `inv`, as in `binoinv` or `expinv`. Specific function names for specific distributions can be found in “Supported Distributions” on page 5-3.

Each function represents a parametric family of distributions. Input arguments are arrays of cumulative probabilities from 0 to 1 followed by a list of parameter values specifying a particular member of the distribution family.

For continuous distributions, the inverse cdf returns the unique outcome whose cdf value is the input cumulative probability.

For example, the `expinv` function can be used to compute inverses of exponential cumulative probabilities:

```
x = 0.5:0.2:1.5 % Outcomes
x =
    0.5000    0.7000    0.9000    1.1000    1.3000    1.5000
p = expcdf(x,1) % Cumulative probabilities
p =
    0.3935    0.5034    0.5934    0.6671    0.7275    0.7769
expinv(p,1) % Return original outcomes
ans =
    0.5000    0.7000    0.9000    1.1000    1.3000    1.5000
```

For discrete distributions, there may be no outcome whose cdf value is the input cumulative probability. In these cases, the inverse cdf returns the first outcome whose cdf value equals or exceeds the input cumulative probability.

For example, the `binoinv` function can be used to compute inverses of binomial cumulative probabilities:

```
x = 0:5 % Some possible outcomes
p = binocdf(x,10,0.2) % Their cumulative probabilities

p =
    0.1074    0.3758    0.6778    0.8791    0.9672    0.9936
q = [.1 .2 .3 .4] % New trial probabilities
```

```
q =  
    0.1000    0.2000    0.3000    0.4000  
  
binoinv(q,10,0.2)    % Their corresponding outcomes  
ans =  
    0     1     1     2
```

The inverse cdf is useful in hypothesis testing, where critical outcomes of a test statistic are computed from cumulative significance probabilities. For example, `norminv` can be used to compute a 95% confidence interval under the assumption of normal variability:

```
p = [0.025 0.975]; % Interval containing 95% of [0,1]  
x = norminv(p,0,1) % Assume standard normal variability  
x =  
   -1.9600    1.9600 % 95% confidence interval  
  
n = 20; % Sample size  
y = normrnd(8,1,n,1); % Random sample (assume mean is unknown)  
ybar = mean(y);  
ci = ybar + (1/sqrt(n))*x % Confidence interval for mean  
ci =  
    7.6779    8.5544
```

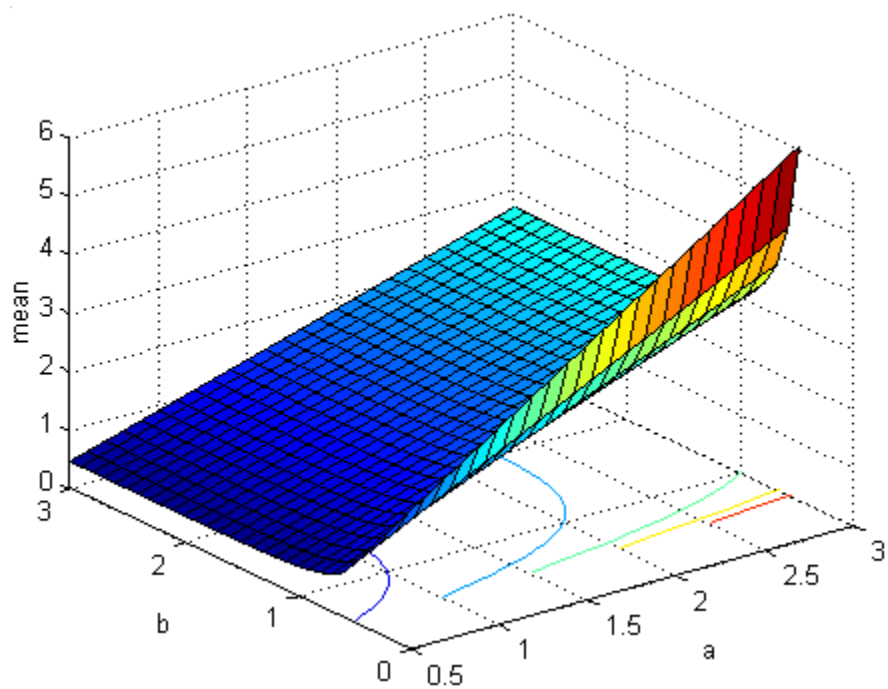
Distribution Statistics Functions

Distribution statistics functions for supported Statistics Toolbox distributions all end with `stat`, as in `binostat` or `expstat`. Specific function names for specific distributions can be found in “Supported Distributions” on page 5-3.

Each function represents a parametric family of distributions. Input arguments are lists of parameter values specifying a particular member of the distribution family. Functions return the mean and variance of the distribution, as a function of the parameters.

For example, the `wblstat` function can be used to visualize the mean of the Weibull distribution as a function of its two distribution parameters:

```
a = 0.5:0.1:3;  
b = 0.5:0.1:3;  
[A,B] = meshgrid(a,b);  
M = wblstat(A,B);  
surf(A,B,M)
```



Distribution Fitting Functions

- “Fitting Regular Distributions” on page 5-71
- “Fitting Piecewise Distributions” on page 5-73

Fitting Regular Distributions

Distribution fitting functions for supported Statistics Toolbox distributions all end with `fit`, as in `binofit` or `expfit`. Specific function names for specific distributions can be found in “Supported Distributions” on page 5-3.

Each function represents a parametric family of distributions. Input arguments are arrays of data, presumed to be samples from some member of the selected distribution family. Functions return maximum likelihood estimates (MLEs) of distribution parameters, that is, parameters for the distribution family member with the maximum likelihood of producing the data as a random sample.

The Statistics Toolbox function `mle` is a convenient front end to the individual distribution fitting functions, and more. The function computes MLEs for distributions beyond those for which Statistics Toolbox software provides specific pdf functions.

For some pdfs, MLEs can be given in closed form and computed directly. For other pdfs, a search for the maximum likelihood must be employed. The search can be controlled with an `options` input argument, created using the `statset` function. For efficient searches, it is important to choose a reasonable distribution model and set appropriate convergence tolerances.

MLEs can be heavily biased, especially for small samples. As sample size increases, however, MLEs become unbiased minimum variance estimators with approximate normal distributions. This is used to compute confidence bounds for the estimates.

For example, consider the following distribution of means from repeated random samples of an exponential distribution:

```
mu = 1; % Population parameter
n = 1e3; % Sample size
ns = 1e4; % Number of samples
```

```
samples = exprnd(mu,n,ns); % Population samples
means = mean(samples); % Sample means
```

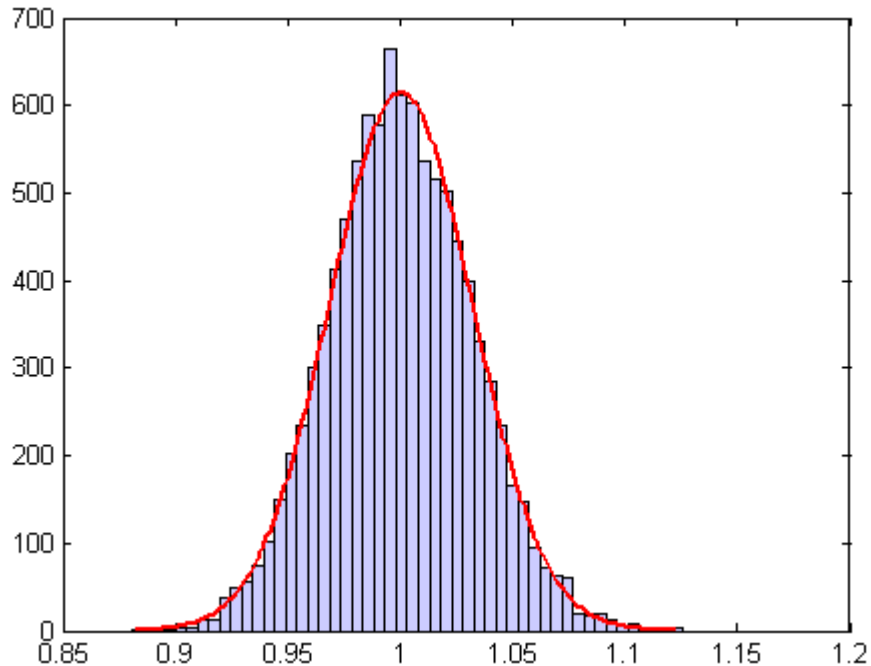
The Central Limit Theorem says that the means will be approximately normally distributed, regardless of the distribution of the data in the samples. The `normfit` function can be used to find the normal distribution that best fits the means:

```
[muhat,sigmahat,muci,sigmaci] = normfit(means)
muhat =
    1.0003
sigmahat =
    0.0319
muci =
    0.9997
    1.0010
sigmaci =
    0.0314
    0.0323
```

The function returns MLEs for the mean and standard deviation and their 95% confidence intervals.

To visualize the distribution of sample means together with the fitted normal distribution, you must scale the fitted pdf, with area = 1, to the area of the histogram being used to display the means:

```
numbins = 50;
hist(means,numbins)
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
hold on
[bincounts,binpositions] = hist(means,numbins);
binwidth = binpositions(2) - binpositions(1);
histarea = binwidth*sum(bincounts);
x = binpositions(1):0.001:binpositions(end);
y = normpdf(x,muhat,sigmahat);
plot(x,histarea*y,'r','LineWidth',2)
```

Fitting Piecewise Distributions

The parametric methods discussed in “Fitting Regular Distributions” on page 5-71 fit data samples with smooth distributions that have a relatively low-dimensional set of parameters controlling their shape. These methods work well in many cases, but there is no guarantee that a given sample will be described accurately by any of the supported Statistics Toolbox distributions.

The empirical distributions computed by `ecdf` and discussed in “Estimating Empirical CDFs” on page 5-64 assign equal probability to each observation in a sample, providing an exact match of the sample distribution. However, the distributions are not smooth, especially in the tails where data may be sparse.

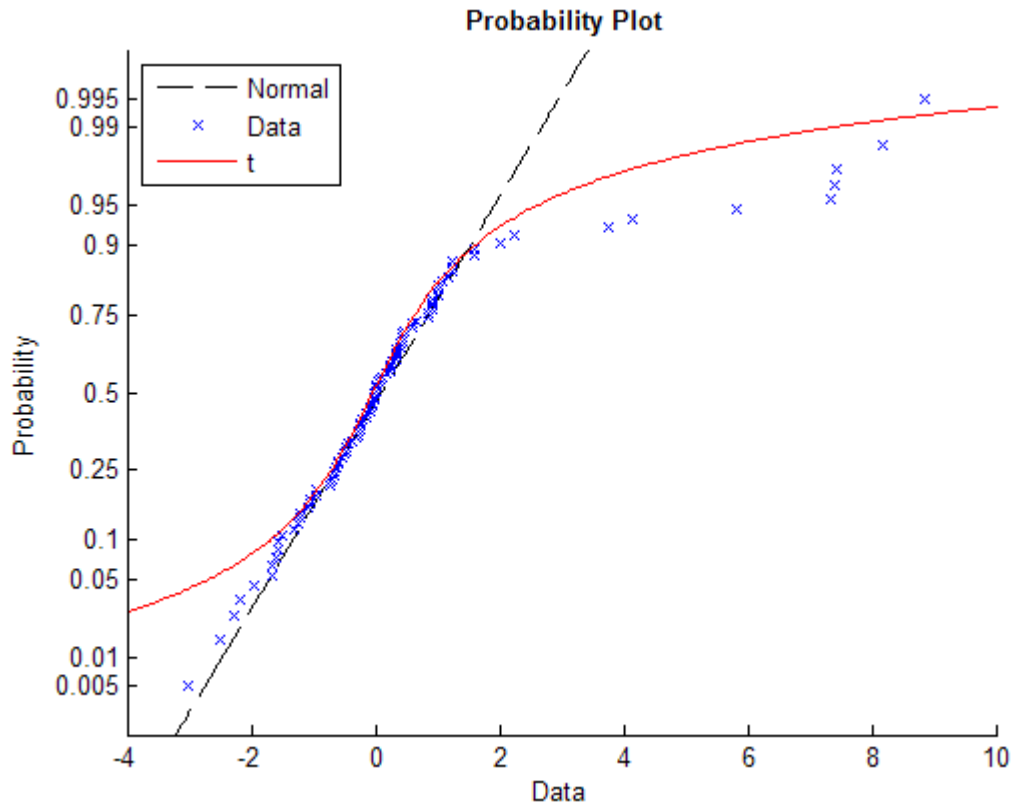
The `paretotails` function fits a distribution by piecing together the empirical distribution in the center of the sample with smooth generalized Pareto distributions (GPDs) in the tails. The output is an object of the `paretotails` class, with associated methods to evaluate the cdf, inverse cdf, and other functions of the fitted distribution.

As an example, consider the following data, with about 20% outliers:

```
left_tail = -exprnd(1,10,1);
right_tail = exprnd(5,10,1);
center = randn(80,1);
data = [left_tail;center;right_tail];
```

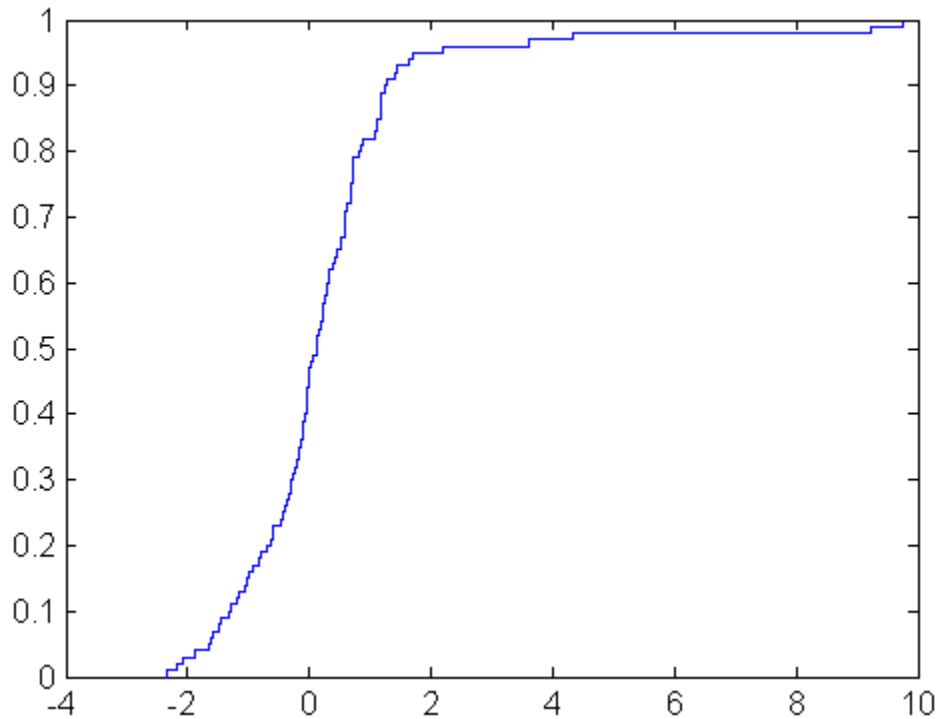
Neither a normal distribution nor a t distribution fits the tails very well:

```
probplot(data);
p = fitdist(data,'tlocationsscale');
h = probplot(gca,p);
set(h,'color','r','linestyle','-')
title('\bf Probability Plot')
legend('Normal','Data','t','Location','NW')
```



On the other hand, the empirical distribution provides a perfect fit, but the outliers make the tails very discrete:

`ecdf(data)`



Random samples generated from this distribution by inversion might include, for example, values around 4.33 and 9.25, but nothing in-between.

The `paretotails` function provides a single, well-fit model for the entire sample. The following uses generalized Pareto distributions (GPDs) for the lower and upper 10% of the data:

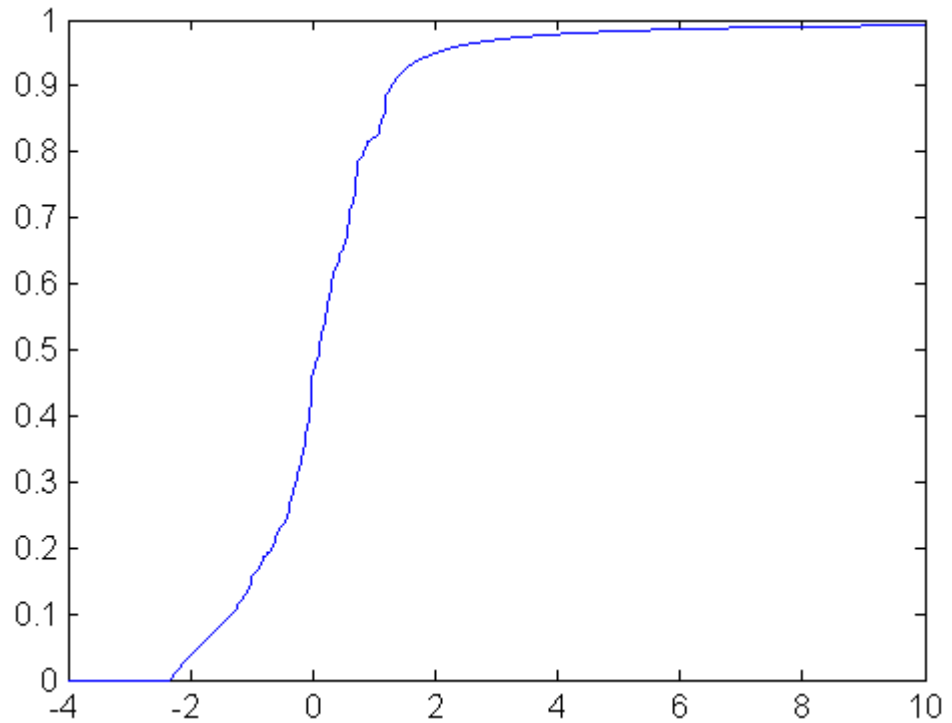
```
pfit = paretotails(data,0.1,0.9)
pfit =
Piecewise distribution with 3 segments
  -Inf < x < -1.30726 (0 < p < 0.1)
      lower tail, GPD(-1.10167,1.12395)

  -1.30726 < x < 1.27213 (0.1 < p < 0.9)
      interpolated empirical cdf

  1.27213 < x < Inf (0.9 < p < 1)
```

```
upper tail, GPD(1.03844,0.726038)
```

```
x = -4:0.01:10;  
plot(x,cdf(pfit,x))
```



Access information about the fit using the methods of the `paretotails` class. Options allow for nonparametric estimation of the center of the cdf.

Negative Log-Likelihood Functions

Negative log-likelihood functions for supported Statistics Toolbox distributions all end with `like`, as in `explike`. Specific function names for specific distributions can be found in “Supported Distributions” on page 5-3.

Each function represents a parametric family of distributions. Input arguments are lists of parameter values specifying a particular member of the distribution family followed by an array of data. Functions return the negative log-likelihood of the parameters, given the data.

Negative log-likelihood functions are used as objective functions in search algorithms such as the one implemented by the MATLAB function `fminsearch`. Additional search algorithms are implemented by Optimization Toolbox™ functions and Global Optimization Toolbox functions.

When used to compute maximum likelihood estimates (MLEs), negative log-likelihood functions allow you to choose a search algorithm and exercise low-level control over algorithm execution. By contrast, the functions discussed in “Distribution Fitting Functions” on page 5-71 use preset algorithms with options limited to those set by the `statset` function.

Likelihoods are conditional probability densities. A parametric family of distributions is specified by its pdf $f(x,a)$, where x and a represent the variables and parameters, respectively. When a is fixed, the pdf is used to compute the density at x , $f(x|a)$. When x is fixed, the pdf is used to compute the *likelihood* of the parameters a , $f(a|x)$. The joint likelihood of the parameters over an independent random sample X is

$$L(a) = \prod_{x \in X} f(a|x)$$

Given X , MLEs maximize $L(a)$ over all possible a .

In numerical algorithms, the log-likelihood function, $\log(L(a))$, is (equivalently) optimized. The logarithm transforms the product of potentially small likelihoods into a sum of logs, which is easier to distinguish from 0 in computation. For convenience, Statistics Toolbox negative log-likelihood functions return the *negative* of this sum, since the optimization algorithms to which the values are passed typically search for minima rather than maxima.

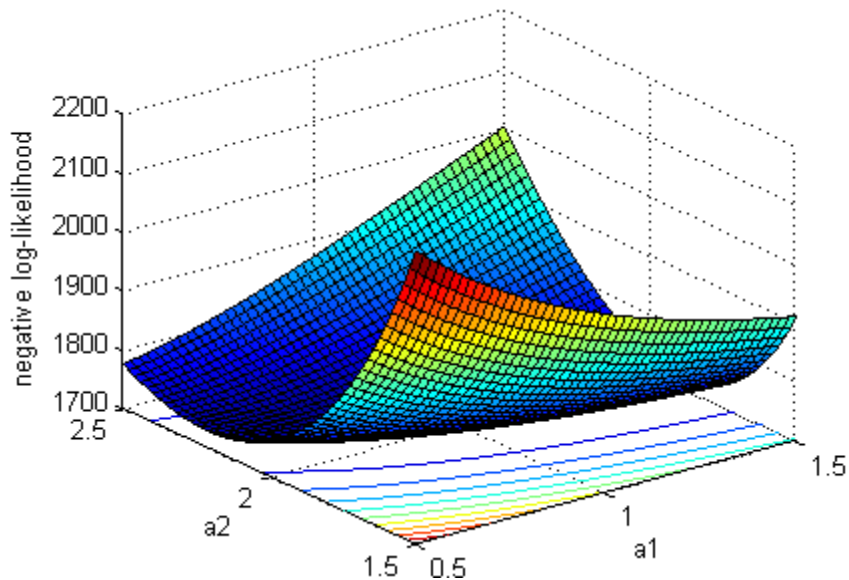
For example, use `gamrnd` to generate a random sample from a specific gamma distribution:

```
a = [1,2];
X = gamrnd(a(1),a(2),1e3,1);
```

Given `X`, the `gamlike` function can be used to visualize the likelihood surface in the neighborhood of `a`:

```
mesh = 50;
delta = 0.5;
a1 = linspace(a(1)-delta,a(1)+delta,mesh);
a2 = linspace(a(2)-delta,a(2)+delta,mesh);
logL = zeros(mesh); % Preallocate memory
for i = 1:mesh
    for j = 1:mesh
        logL(i,j) = gamlike([a1(i),a2(j)],X);
    end
end

[A1,A2] = meshgrid(a1,a2);
surfc(A1,A2,logL)
```



The MATLAB function `fminsearch` is used to search for the minimum of the likelihood surface:

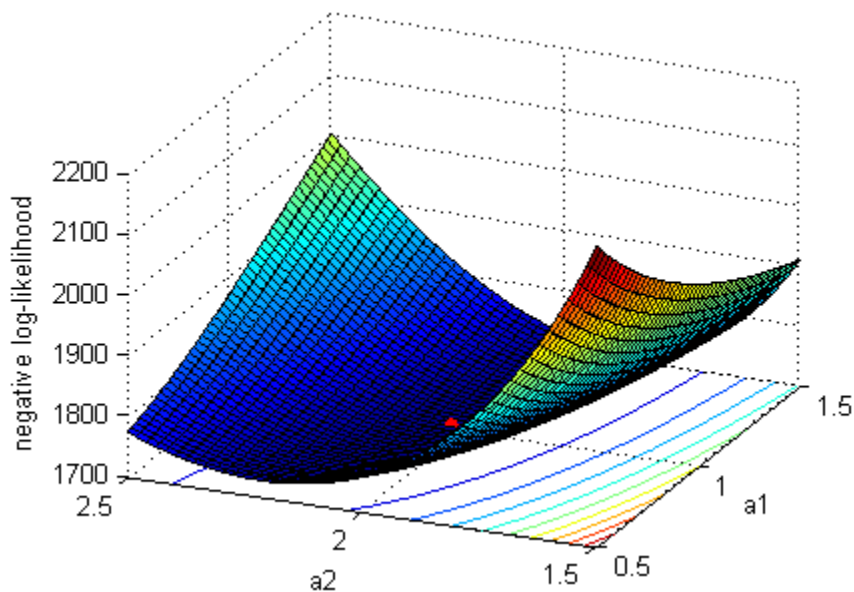
```
LL = @(u)gamlike([u(1),u(2)],X); % Likelihood given X
MLES = fminsearch(LL,[1,2])
MLES =
    1.0231    1.9729
```

These can be compared to the MLEs returned by the `gamfit` function, which uses a combination search and solve algorithm:

```
ahat = gamfit(X)
ahat =
    1.0231    1.9728
```

The MLEs can be added to the surface plot (rotated to show the minimum):

```
hold on
plot3(MLES(1),MLES(2),LL(MLES),...
      'ro','MarkerSize',5,...
      'MarkerFaceColor','r')
```



Random Number Generators

The Statistics Toolbox supports the generation of random numbers from various distributions. Each RNG represents a parametric family of distributions. RNGs return random numbers from the specified distribution in an array of the specified dimensions. Specific RNG names for specific distributions are in “Supported Distributions” on page 5-3.

Other random number generation functions which do not support specific distributions include:

- `cvpartition`
- `datasample`
- `hmmgenerate`
- `lhsdesign`
- `lhsnorm`
- `mhsample`
- `random`
- `randsample`
- `slicesample`

RNGs in Statistics Toolbox software depend on MATLAB’s default random number stream via the `rand` and `randn` functions, each RNG uses one of the techniques discussed in “Common Generation Methods” on page 6-5 to generate random numbers from a given distribution.

By controlling the default random number stream and its state, you can control how the RNGs in Statistics Toolbox software generate random values. For example, to reproduce the same sequence of values from an RNG, you can save and restore the default stream’s state, or reset the default stream. For details on managing the default random number stream, see “Managing the Global Stream”.

MATLAB initializes the default random number stream to the same state each time it starts up. Thus, RNGs in Statistics Toolbox software will generate the same sequence of values for each MATLAB session unless you

modify that state at startup. One simple way to do that is to add commands to `startup.m` such as

```
rng('shuffle');
```

that initialize MATLAB's default random number stream to a different state for each session.

Dependencies of the Random Number Generators

The following table lists the dependencies of Statistics Toolbox RNGs on the MATLAB base RNGs `rand`, `randi`, and/or `randn`.

RNG	MATLAB Base RNG
<code>betarnd</code>	<code>rand</code> , <code>randn</code>
<code>binornd</code>	<code>rand</code>
<code>chi2rnd</code>	<code>rand</code> , <code>randn</code>
<code>evrnd</code>	<code>rand</code>
<code>exprnd</code>	<code>rand</code>
<code>datasample</code>	<code>rand</code> , <code>randi</code> , <code>randperm</code>
<code>frnd</code>	<code>rand</code> , <code>randn</code>
<code>gamrnd</code>	<code>rand</code> , <code>randn</code>
<code>geornd</code>	<code>rand</code>
<code>gevrnd</code>	<code>rand</code>
<code>gprnd</code>	<code>rand</code>
<code>hygernd</code>	<code>rand</code>
<code>iwishrnd</code>	<code>rand</code> , <code>randn</code>
<code>johnsrnd</code>	<code>randn</code>
<code>lhsdesign</code>	<code>rand</code>
<code>lhsnorm</code>	<code>rand</code>
<code>lognrnd</code>	<code>randn</code>
<code>mhsample</code>	<code>rand</code> or <code>randn</code> , depending on the RNG given for the proposal distribution
<code>mvnrnd</code>	<code>randn</code>
<code>mvtrnd</code>	<code>rand</code> , <code>randn</code>

RNG	MATLAB Base RNG
nbinrnd	rand, randn
ncfrnd	rand, randn
nctrnd	rand, randn
ncx2rnd	randn
normrnd	randn
pearsrnd	rand or randn, depending on the distribution type
poissrnd	rand, randn
random	rand or randn, depending on the specified distribution
randsample	rand
raylrnd	randn
slicesample	rand
trnd	rand, randn
unidrnd	rand
unifrnd	rand
wblrnd	rand
wishrnd	rand, randn

Using Probability Distribution Objects

In this section...

“Using Distribution Objects” on page 5-85

“What are Objects?” on page 5-86

“Creating Distribution Objects” on page 5-89

“Object-Supported Distributions” on page 5-90

“Performing Calculations Using Distribution Objects” on page 5-91

“Capturing Results Using Distribution Objects” on page 5-98

Using Distribution Objects

For many distributions supported by Statistics Toolbox software, objects are available for statistical analysis. This section gives a general overview of the uses of distribution objects, including sample work flows. For information on objects available for specific distributions, see “Object-Supported Distributions” on page 5-90.

Probability distribution objects allow you to easily fit, access, and store distribution information for a given data set. The following operations are easier to perform using distribution objects:

- Grouping a single dataset in a number of different ways using group names, and then fit a distribution to each group. For an example of how to fit distributions to grouped data, see “Example: Fitting Distributions to Grouped Data Within a Single Dataset” on page 5-92.
- Fitting different distributions to the same set of data. For an example of how objects make fitting multiple distribution types easier, see “Example: Fitting Multiple Distribution Types to a Single Dataset” on page 5-96.
- Sharing fitted distributions across workspaces. For an example of sharing information using probability distribution objects, see “Example: Saving and Sharing Distribution Fit Data” on page 5-98.

Deciding to Use Distribution Objects

If you know the type of distribution you would like to use, objects provide a less complex interface than functions and a more efficient functionality than the `dfittool` GUI.

If you are a novice statistician who would like to explore how various distributions look without having to manipulate data, see “Working with Distributions Through GUIs” on page 5-10.

If you have no data to fit, but want to calculate a `pdf`, `cdf`, etc for various parameters, see “Statistics Toolbox Distribution Functions” on page 5-53.

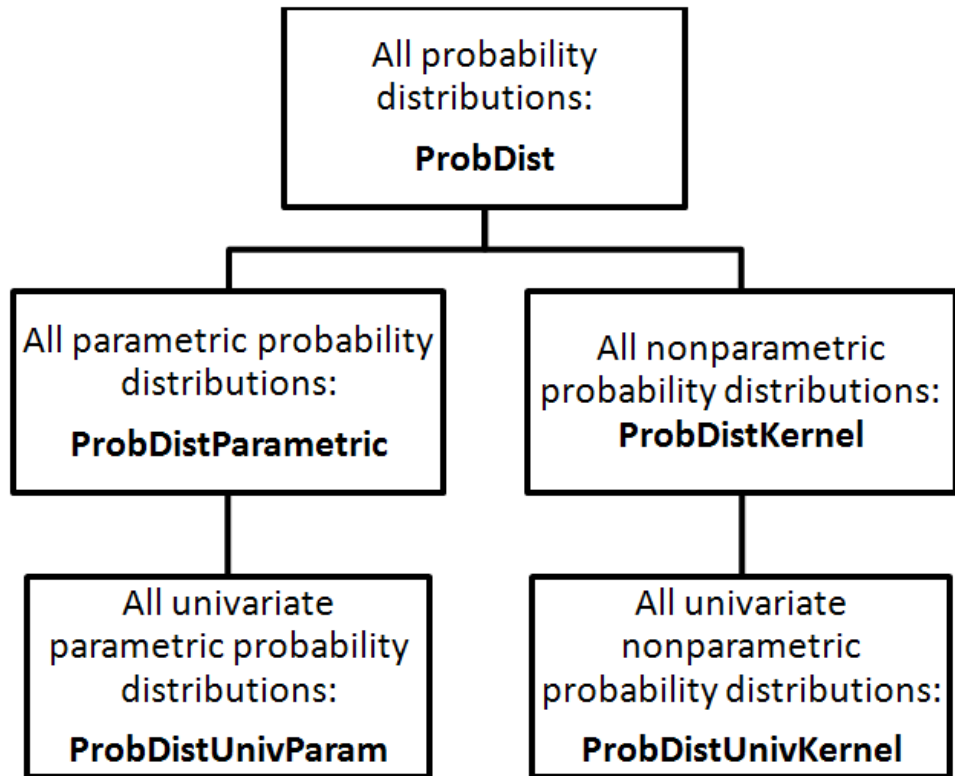
What are Objects?

Objects are, in short, a convenient way of storing data. They allow you to set rules for the types of data to store, while maintaining some flexibility for the actual values of the data. For example, in statistics groups of distributions have some general things in common:

- All distributions have a name (ex, Normal).
- Parametric distributions have parameters.
- Nonparametric distributions have kernel-smoothing functions.

Objects store all this information within properties. Classes of related objects (for example, all univariate parametric distributions) have the same properties with values and types relevant to a specified distribution. In addition to storing information within objects, you can perform certain actions (called *methods*) on objects.

Subclasses (for example, `ProbDistParametric` is a subclass of `ProbDist`) contain the same properties and methods as the original class, in addition to other properties relevant to that subclass. This concept is called *inheritance*. Inheritance means that subclasses of a class have all of its properties and methods. For example, parametric distributions, which are a subset (subclass) of probability distributions, have input data and a distribution name. The following diagram illustrates this point:



The left side of this diagram shows the inheritance line from all probability distributions down to univariate parametric probability distributions. The right side shows the lineage down to univariate kernel distributions. Here is how to interpret univariate parametric distribution lineage:

- **ProbDist** is a class of objects that includes all probability distributions. All probability distribution objects have at least these properties:
 - **DistName** — the name of the distribution (for example Normal or Weibull)
 - **InputData** — the data fit to the distribution
 In addition, you can perform the following actions on these objects, using the following methods:
 - **cdf** — Return the cumulative distribution function for a specified distribution.

- `pdf` — Return the probability density function for a specified distribution.
- `random` — Generate random numbers based on a specified distribution.
- `ProbDistParametric` is a class of objects that includes all parametric probability distributions. All parametric probability distribution objects have the properties and methods of a `ProbDist` object, in addition to at least the following properties:
 - `NLogL` — Negative log likelihood for input data
 - `NumParams` — Number of parameters for that distribution
 - `ParamCov` — Covariance matrix of parameter estimates
 - `ParamDescription` — Descriptions of parameters
 - `ParamNames` — Names of parameters
 - `Params` — Values of parametersNo additional unique methods apply to `ProbDistParametric` objects.
- `ProbDistUnivParam` is a class of objects that includes only univariate parametric probability distributions. In addition to the properties and methods of `ProbDist` and `ProbDistParametric` objects, these objects also have at least the following methods:
 - `icdf` — Return the inverse cumulative distribution function for a specified distribution based on a given set of data.
 - `iqr` — Return the interquartile range for a specified distribution based on a given set of data.
 - `mean` — Return the mean for a specified distribution based on a given set of data.
 - `median` — Return the median for a specified distribution based on a given set of data.
 - `paramci` — Return the parameter confidence intervals for a specified distribution based on a given set of data.
 - `std` — Return the standard deviation for a specified distribution based on a given set of data.
 - `var` — Return the variance for a specified distribution based on a given set of data.No additional unique properties apply to `ProbDistUnivParam` objects.

The univariate nonparametric lineage reads in a similar manner, with different properties and methods. For more information on nonparametric objects and their methods and properties, see `ProbDistKernel` and `ProbDistUnivKernel`.

Creating Distribution Objects

There are two ways to create distribution objects:

- Use the `fitdist` function. See “Creating Distribution Objects Using `fitdist`” on page 5-89.
- Use the object constructor. See “Creating Distribution Objects Using Constructors” on page 5-89.

Creating Distribution Objects Using `fitdist`

Using the `fitdist` function is the simplest way of creating distribution objects. Like the `*fit` functions, `fitdist` fits your data to a specified distribution and returns relevant distribution information. `fitdist` creates an object relevant to the type of distribution you specify: if you specify a parametric distribution, it returns a `ProbDistUnivParam` object. For examples of how to use `fitdist` to fit your data, see “Performing Calculations Using Distribution Objects” on page 5-91.

Creating Distribution Objects Using Constructors

If you know the distribution you would like to use and would like to create a univariate parametric distribution with known parameters, you can use the `ProbDistUnivParam` constructor. For example, create a normal distribution with mean 100 and standard deviation 10:

```
pd = ProbDistUnivParam('normal',[100 10])
```

For nonparametric distributions, you must have a dataset. Using `fitdist` is a simpler way to fit nonparametric data, but you can use the `ProbDistUnivKernel` constructor as well. For example, create a nonparametric distribution of the MPG data from `carsmall.mat`:

```
load carsmall
pd = ProbDistUnivKernel(MPG)
```

Object-Supported Distributions

Object-oriented programming in the Statistics Toolbox supports the following distributions.

Parametric Distributions

Use the following distribution to create `ProbDistUnivParam` objects using `fitdist`. For more information on the cumulative distribution function (`cdf`) and probability density function (`pdf`) methods, as well as other available methods, see the `ProbDistUnivParam` class reference page.

Supported Distribution	Input to <code>fitdist</code>
“Beta Distribution” on page B-4	'beta'
“Binomial Distribution” on page B-7	'binomial'
“Birnbbaum-Saunders Distribution” on page B-10	'birnbaumsaunders'
“Burr Type XII Distribution” on page B-12	'burr'
“Exponential Distribution” on page B-29	'exponential'
“Extreme Value Distribution” on page B-32	'extreme value' or 'ev'
“Gamma Distribution” on page B-40	'gamma'
“Generalized Extreme Value Distribution” on page B-45	'generalized extreme value' or 'gev'
“Generalized Pareto Distribution” on page B-50	'generalized pareto' or 'gp'
“Inverse Gaussian Distribution” on page B-58	'inversegaussian'
“Logistic Distribution” on page B-62	'logistic'
“Loglogistic Distribution” on page B-63	'loglogistic'

Supported Distribution	Input to fitdist
“Lognormal Distribution” on page B-64	'lognormal'
“Nakagami Distribution” on page B-83	'nakagami'
“Negative Binomial Distribution” on page B-85	'negative binomial' or 'nbin'
“Normal Distribution” on page B-96	'normal'
“Poisson Distribution” on page B-102	'poisson'
“Rayleigh Distribution” on page B-104	'rayleigh'
“Rician Distribution” on page B-106	'rician'
“t Location-Scale Distribution” on page B-110	'tlocationscale'
“Weibull Distribution” on page B-116	'weibull' or 'wbl'

Nonparametric Distributions

Use the following distributions to create `ProbDistUnivKernel` objects. For more information on the cumulative distribution function (cdf) and probability density function (pdf) methods, as well as other available methods, see the `ProbDistUnivKernel` class reference page.

Supported Distribution	Input to fitdist
“Nonparametric Distributions” on page B-95	'kernel'

Performing Calculations Using Distribution Objects

Distribution objects make it easier for you to perform calculations on complex datasets. The following sample workflows show some of the functionality of these objects.

- “Example: Fitting a Single Distribution to a Single Dataset” on page 5-92

- “Example: Fitting Distributions to Grouped Data Within a Single Dataset” on page 5-92
- “Example: Fitting Multiple Distribution Types to a Single Dataset” on page 5-96

Example: Fitting a Single Distribution to a Single Dataset

Fit a single Normal distribution to a dataset using `fitdist`:

```
load carsmall
NormDist = fitdist(MPG, 'normal')
```

```
NormDist =
```

```
normal distribution
```

```
mu = 23.7181
sigma = 8.03573
```

The output MATLAB returns is a `ProbDistUnivParam` object with a `DistName` property of 'normal distribution'. The `ParamNames` property contains the strings `mu` and `sigma`, while the `Params` property contains the parameter values.

Example: Fitting Distributions to Grouped Data Within a Single Dataset

Often, datasets are collections of data you can group in different ways. Using `fitdist` and the data from `carsmall.mat`, group the MPG data by country of origin, then fit a Weibull distribution each group:

```
load carsmall
[WeiByOrig, Country] = fitdist(MPG, 'weibull', 'by', Origin)
Warning: Error while fitting group 'Italy':
Not enough data in X to fit this distribution.
> In fitdist at 171
```

```
WeiByOrig =
```

Columns 1 through 4

```
[1x1 ProbDistUnivParam]    [1x1 ProbDistUnivParam] ...
      [1x1 ProbDistUnivParam]    [1x1 ProbDistUnivParam]
```

Columns 5 through 6

```
[1x1 ProbDistUnivParam]    []
```

Country =

```
'USA'
'France'
'Japan'
'Germany'
'Sweden'
'Italy'
```

A warning appears informing you that, since the data only represents one Italian car, `fitdist` cannot fit a Weibull distribution to that group. Each one of the five other groups now has a distribution object associated with it, represented in the cell array `wd`. Each object contains properties that hold information about the data, the distribution, and the parameters. For more information on what properties exist and what information they contain, see `ProbDistUnivParam` or `ProbDistUnivKernel`.

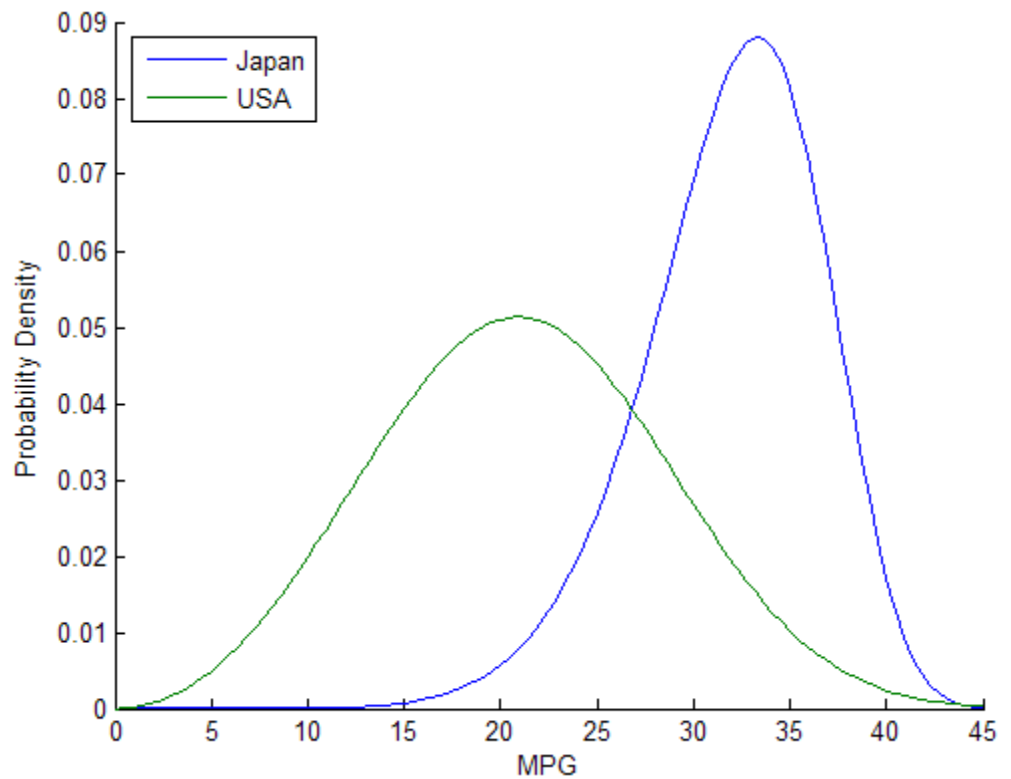
Now access two of the objects and their properties:

```
% Get USA fit
distusa = WeiByOrig{1};
% Use the InputData property of ProbDistUnivParam objects to see
% the actual data used to fit the distribution:
dusa = distusa.InputData.data;

% Get Japan fit and data
distjapan = WeiByOrig{3};
djapan = distjapan.InputData.data;
```

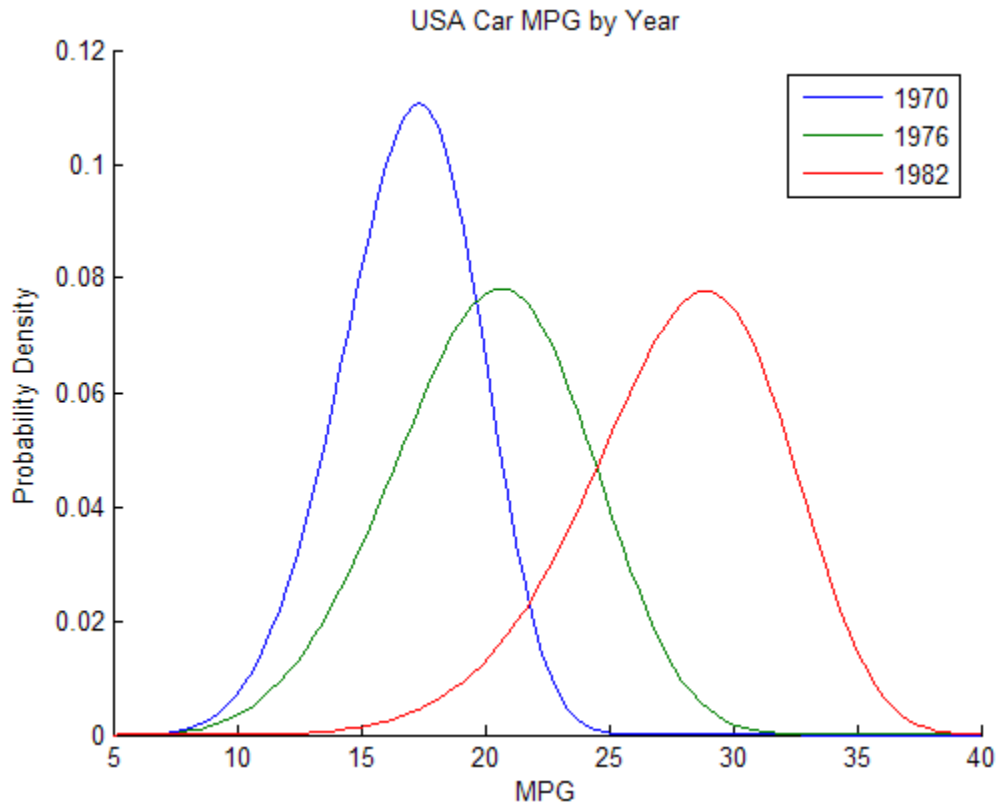
Now you can easily compare PDFs using the pdf method of the ProbDistUnivParam class:

```
time = linspace(0,45);  
pdfjapan = pdf(distjapan,time);  
pdfusa = pdf(distusa,time);  
hold on  
plot(time,[pdfjapan;pdfusa])  
l = legend('Japan','USA')  
set(l,'Location','Best')  
xlabel('MPG')  
ylabel('Probability Density')
```



You could then further group the data and compare, for example, MPG by year for American cars:

```
load carsmall
[WeiByYearOrig, Names] = fitdist(MPG, 'weibull', 'by', ...
    {Origin Model_Year});
USA70 = WeiByYearOrig{1};
USA76 = WeiByYearOrig{2};
USA82 = WeiByYearOrig{3};
time = linspace(0,45);
pdf70 = pdf(USA70,time);
pdf76 = pdf(USA76,time);
pdf82 = pdf(USA82,time);
line(t,[pdf70;pdf76;pdf82])
l = legend('1970','1976','1982')
set(l,'Location','Best')
title('USA Car MPG by Year')
xlabel('MPG')
ylabel('Probability Density')
```



Example: Fitting Multiple Distribution Types to a Single Dataset

Distribution objects make it easy to fit multiple distributions to the same dataset, while minimizing workspace clutter. For example, use `fitdist` to group the MPG data by country of origin, then fit Weibull, Normal, Logistic, and nonparametric distributions for each group:

```
load carsmall;  
[WeiByOrig, Country] = fitdist(MPG, 'weibull', 'by', Origin);  
[NormByOrig, Country] = fitdist(MPG, 'normal', 'by', Origin);  
[LogByOrig, Country] = fitdist(MPG, 'logistic', 'by', Origin);  
[KerByOrig, Country] = fitdist(MPG, 'kernel', 'by', Origin);
```

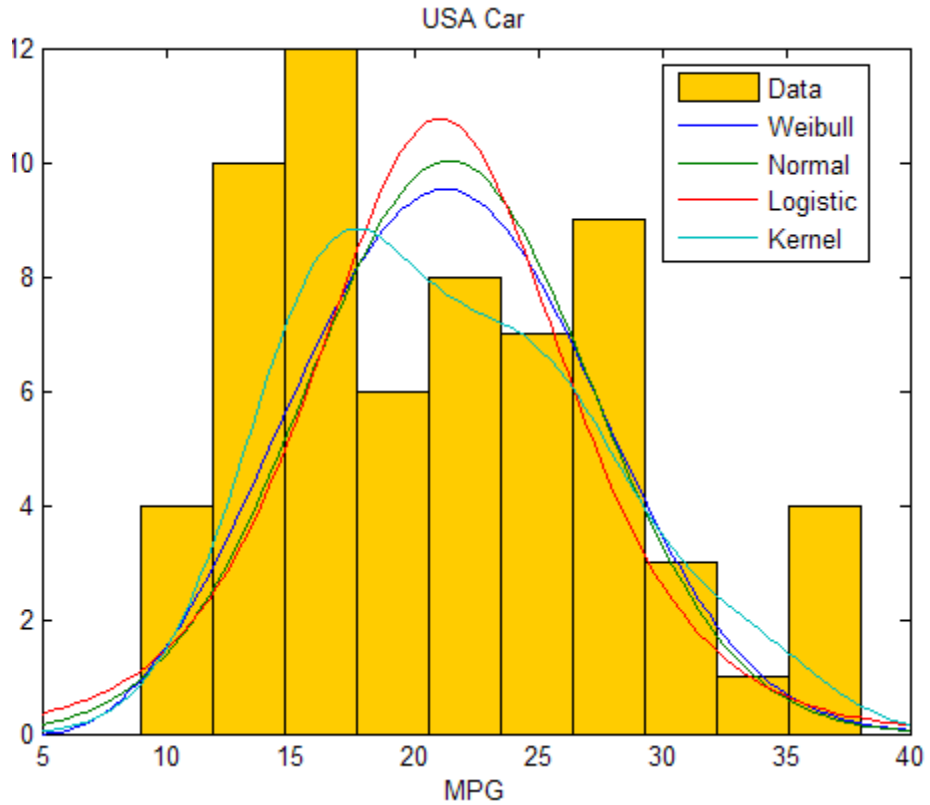

Extract the fits for American cars and compare the fits visually against a histogram of the original data:

```
WeiUSA = WeiByOrig{1};
NormUSA = NormByOrig{1};
LogUSA = LogByOrig{1};
KerUSA = KerByOrig{1};

% Since all three distributions use the same set of data,
% you can extract the data from any of them:
data = WeiUSA.InputData.data;

% Create a histogram of the data:
[n,y] = hist(data,10);
b = bar(y,n,'hist');
set(b,'FaceColor',[1,0.8,0])

% Scale the density by the histogram area, for easier display:
area = sum(n) * (y(2)-y(1));
time = linspace(0,45);
pdfWei = pdf(WeiUSA,time);
pdfNorm = pdf(NormUSA,time);
pdfLog = pdf(LogUSA,time);
pdfKer = pdf(KerUSA,time);
allpdf = [pdfWei;pdfNorm;pdfLog;pdfKer];
line(t,area * allpdf)
l = legend('Data','Weibull','Normal','Logistic','Kernel')
set(l,'Location','Best')
title('USA Car')
xlabel('MPG')
```



You can see that only the nonparametric kernel distribution, KerUSA, comes close to revealing the two modes in the data.

Capturing Results Using Distribution Objects

Distribution objects allow you to share both your dataset and your analysis results simply by saving the information to a .mat file.

Example: Saving and Sharing Distribution Fit Data

Using the premise from the previous set of examples, group the MPG data in carsmall.mat by country of origin and fit four different distributions to each of the six sets of data:

```
load carsmall;
[WeiByOrig, Country] = fitdist(MPG,'weibull','by',Origin);
[NormByOrig, Country] = fitdist(MPG,'normal','by',Origin);
[LogByOrig, Country] = fitdist(MPG,'logistic','by',Origin);
[KerByOrig, Country] = fitdist(MPG,'kernel','by',Origin);
```

Combine all four fits and the country labels into a single cell array, including “headers” to indicate which distributions correspond to which objects. Then, save the array to a .mat file:

```
AllFits = cell(['Country' Country'; 'Weibull' WeiByOrig;...
               'Normal' NormByOrig; 'Logistic' LogByOrig; 'Kernel',...
               KerByOrig]);
save('CarSmallFits.mat','AllFits');
```

To show that the data is both safely saved and easily restored, clear your workspace of relevant variables. This command clears only those variables associated with this example:

```
clear('Weight','Acceleration','AllFits','Country',...
      'Cylinders','Displacement','Horsepower','KerByOrig',...
      'LogByOrig','MPG','Model','Model_Year','NormByOrig',...
      'Origin','WeiByOrig')
```

Now, load the data:

```
load CarSmallFits
AllFits
```

You can now access the distributions objects as in the previous examples.

Probability Distributions Used for Multivariate Modeling

In this section...
“Gaussian Mixture Models” on page 5-100
“Copulas: Generate Correlated Samples” on page 5-108

Gaussian Mixture Models

- “Creating Gaussian Mixture Models” on page 5-100
- “Simulating Gaussian Mixtures” on page 5-106

Gaussian mixture models are formed by combining multivariate normal density components. For information on individual multivariate normal densities, see “Multivariate Normal Distribution” on page B-71 and related distribution functions listed under “Multivariate Distributions” on page 5-9.

In Statistics Toolbox software, use the `gmdistribution` class to fit data using an expectation maximization (EM) algorithm, which assigns posterior probabilities to each component density with respect to each observation. The fitting method uses an iterative algorithm that converges to a local optimum. Clustering using Gaussian mixture models is sometimes considered a soft clustering method. The posterior probabilities for each point indicate that each data point has some probability of belonging to each cluster.

For more information on clustering with Gaussian mixture models, see “Gaussian Mixture Models” on page 11-28. This section describes their creation.

Creating Gaussian Mixture Models

- “Specifying a Model” on page 5-101
- “Fitting a Model to Data” on page 5-103

Specifying a Model. Use the `gmdistribution` constructor to create Gaussian mixture models with specified means, covariances, and mixture proportions. The following creates an object of the `gmdistribution` class defining a two-component mixture of bivariate Gaussian distributions:

```
MU = [1 2;-3 -5]; % Means
SIGMA = cat(3,[2 0;0 .5],[1 0;0 1]); % Covariances
p = ones(1,2)/2; % Mixing proportions

obj = gmdistribution(MU,SIGMA,p);
```

Display properties of the object with the MATLAB function `fieldnames`:

```
properties = fieldnames(obj)
properties =
    'NDimensions'
    'DistName'
    'NComponents'
    'PComponents'
    'mu'
    'Sigma'
    'NlogL'
    'AIC'
    'BIC'
    'Converged'
    'Iters'
    'SharedCov'
    'CovType'
    'RegV'
```

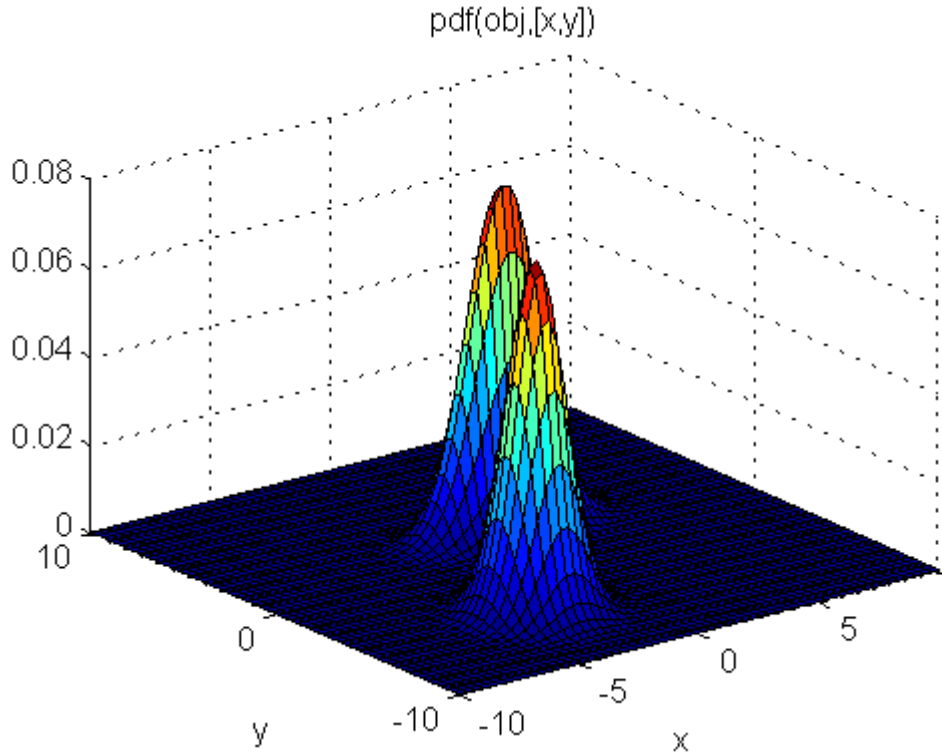
The `gmdistribution` reference page describes these properties. To access the value of a property, use dot indexing:

```
dimension = obj.NDimensions
dimension =
    2

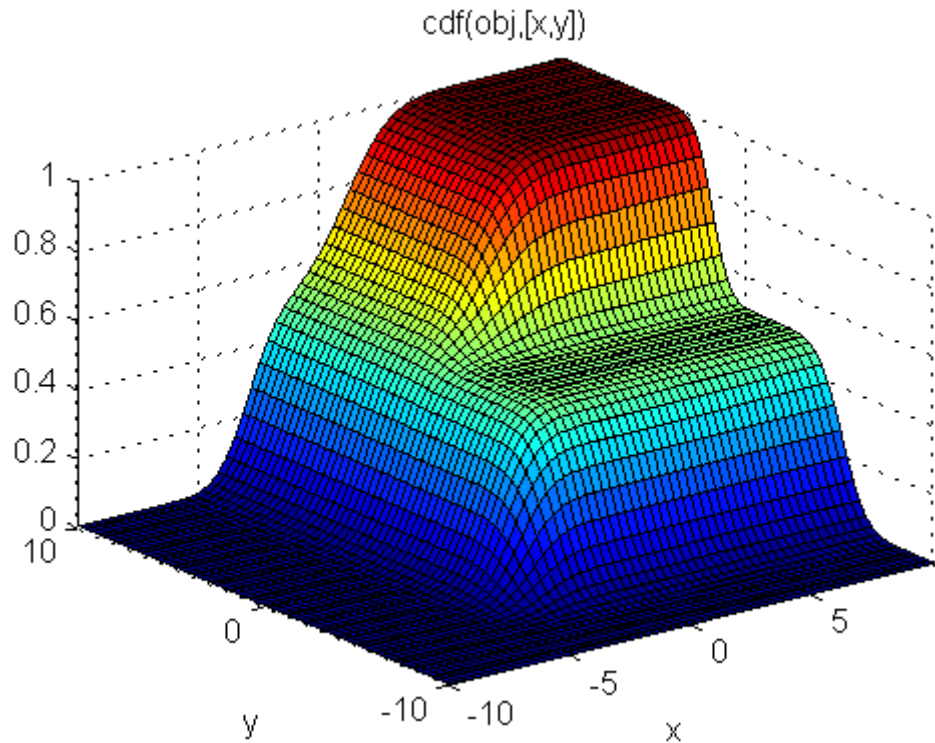
name = obj.DistName
name =
gaussian mixture distribution
```

Use the methods pdf and cdf to compute values and visualize the object:

```
ezsurf(@(x,y)pdf(obj,[x y]),[-10 10],[-10 10])
```



```
ezsurf(@(x,y)cdf(obj,[x y]),[-10 10],[-10 10])
```



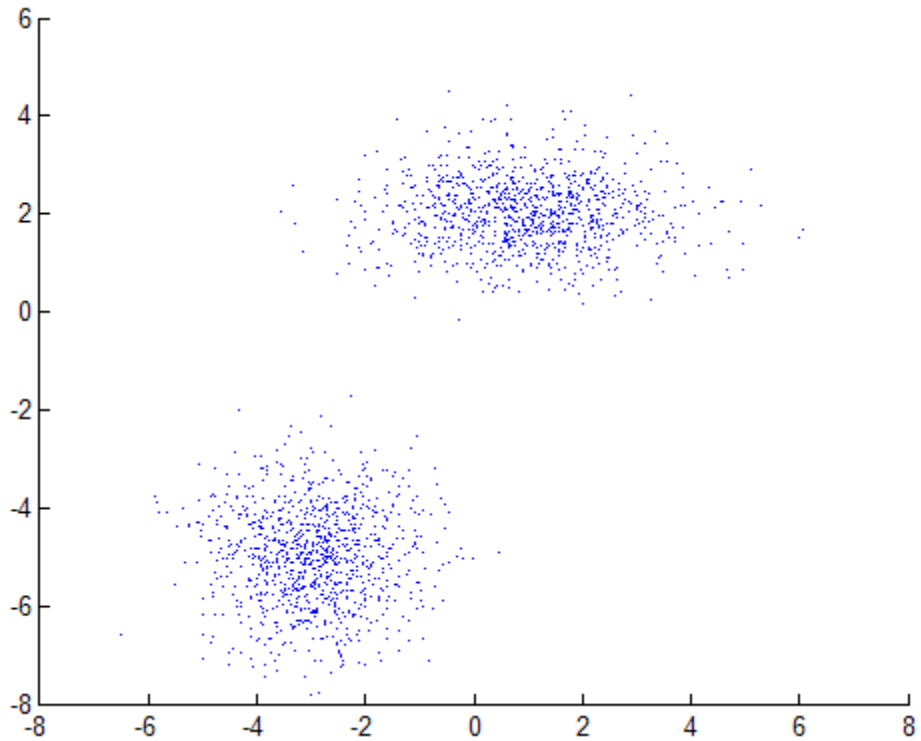
Fitting a Model to Data. You can also create Gaussian mixture models by fitting a parametric model with a specified number of components to data. The `fit` method of the `gmdistribution` class uses the syntax `obj = gmdistribution.fit(X,k)`, where `X` is a data matrix and `k` is the specified number of components. Choosing a suitable number of components `k` is essential for creating a useful model of the data—too few components fails to model the data accurately; too many components leads to an over-fit model with singular covariance matrices.

The following example illustrates this approach.

First, create some data from a mixture of two bivariate Gaussian distributions using the `mvnrnd` function:

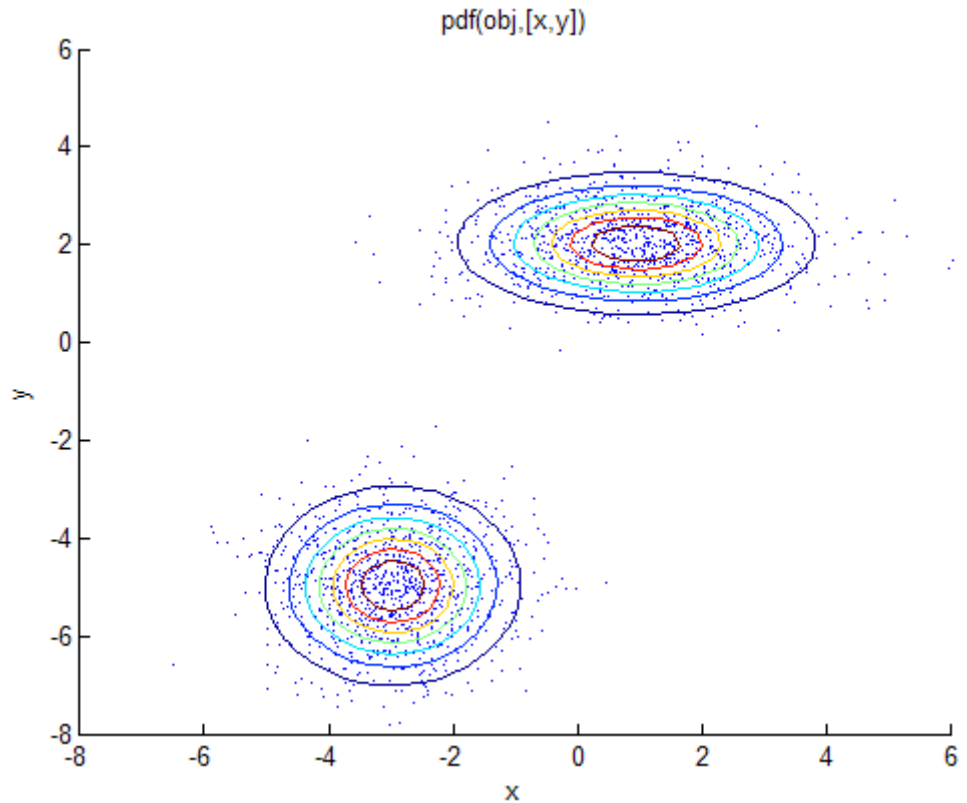
```
MU1 = [1 2];  
SIGMA1 = [2 0; 0 .5];
```

```
MU2 = [-3 -5];  
SIGMA2 = [1 0; 0 1];  
X = [mvnrnd(MU1,SIGMA1,1000);  
mvnrnd(MU2,SIGMA2,1000)];  
scatter(X(:,1),X(:,2),10,'.')
```



Next, fit a two-component Gaussian mixture model:

```
options = statset('Display','final');  
obj = gmdistribution.fit(X,2,'Options',options);  
hold on  
h = ezcontour(@(x,y)pdf(obj,[x y]),[-8 6],[-8 6]);  
hold off
```

Among the properties of the fit are the parameter estimates:

```
ComponentMeans = obj.mu
```

```
ComponentMeans =
```

```
    0.9391    2.0322
```

```
   -2.9823   -4.9737
```

```
ComponentCovariances = obj.Sigma
```

```
ComponentCovariances(:, :, 1) =
```

```
    1.7786   -0.0528
```

```
   -0.0528    0.5312
```

```
ComponentCovariances(:, :, 2) =
```

```
    1.0491   -0.0150
```

```
-0.0150    0.9816
```

```
MixtureProportions = obj.PComponents  
MixtureProportions =  
    0.5000    0.5000
```

The two-component model minimizes the Akaike information:

```
AIC = zeros(1,4);  
obj = cell(1,4);  
for k = 1:4  
    obj{k} = gmdistribution.fit(X,k);  
    AIC(k) = obj{k}.AIC;  
end  
  
[minAIC,numComponents] = min(AIC);  
numComponents  
numComponents =  
    2  
  
model = obj{2}  
model =  
Gaussian mixture distribution  
with 2 components in 2 dimensions  
Component 1:  
Mixing proportion: 0.500000  
Mean:    0.9391    2.0322  
Component 2:  
Mixing proportion: 0.500000  
Mean:   -2.9823   -4.9737
```

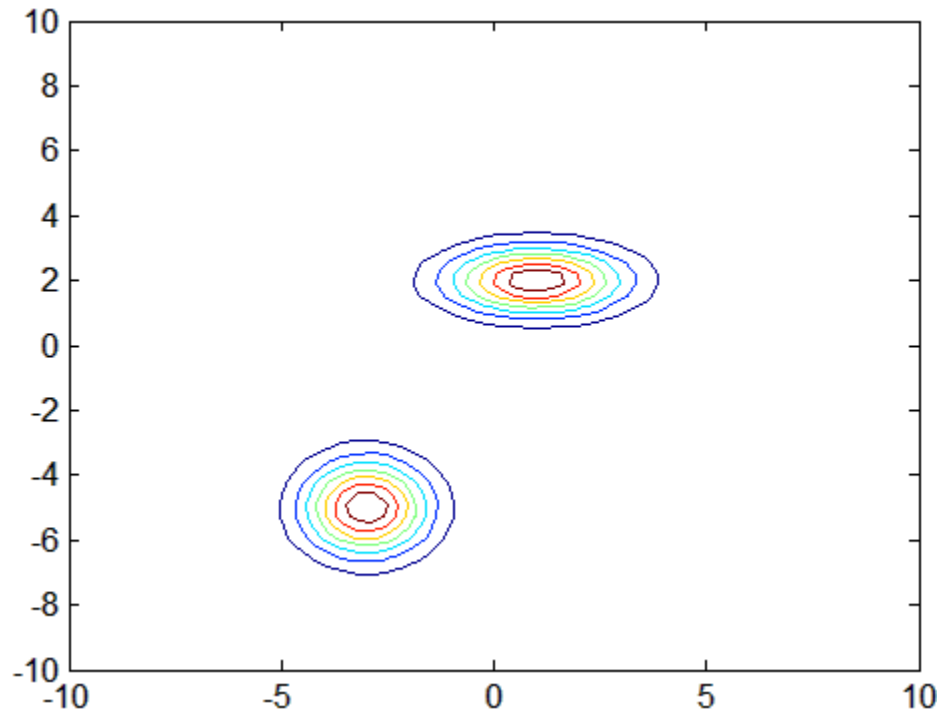
Both the Akaike and Bayes information are negative log-likelihoods for the data with penalty terms for the number of estimated parameters. You can use them to determine an appropriate number of components for a model when the number of components is unspecified.

Simulating Gaussian Mixtures

Use the method `random` of the `gmdistribution` class to generate random data from a Gaussian mixture model created with `gmdistribution` or `fit`.

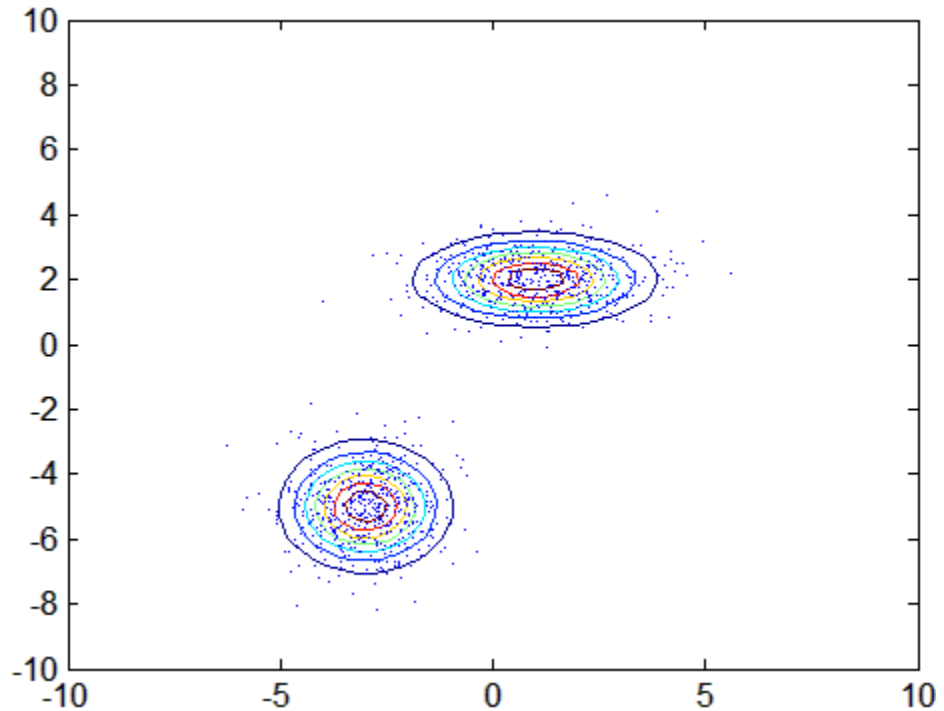
For example, the following specifies a `gmdistribution` object consisting of a two-component mixture of bivariate Gaussian distributions:

```
MU = [1 2; -3 -5];  
SIGMA = cat(3,[2 0;0 .5],[1 0;0 1]);  
p = ones(1,2)/2;  
obj = gmdistribution(MU,SIGMA,p);  
  
ezcontour(@(x,y)pdf(obj,[x y]),[-10 10],[-10 10])  
hold on
```



Use `random (gmdistribution)` to generate 1000 random values:

```
Y = random(obj,1000);  
  
scatter(Y(:,1),Y(:,2),10,'.')
```



Copulas: Generate Correlated Samples

- “Determining Dependence Between Simulation Inputs” on page 5-109
- “Constructing Dependent Bivariate Distributions” on page 5-113
- “Using Rank Correlation Coefficients” on page 5-117
- “Using Bivariate Copulas” on page 5-120
- “Higher Dimension Copulas” on page 5-127
- “Archimedean Copulas” on page 5-129
- “Simulating Dependent Multivariate Data Using Copulas” on page 5-131
- “Example: Fitting Copulas to Data” on page 5-136

Copulas are functions that describe dependencies among variables, and provide a way to create distributions that model correlated multivariate data. Using a copula, you can construct a multivariate distribution by specifying marginal univariate distributions, and then choose a copula to provide a correlation structure between variables. Bivariate distributions, as well as distributions in higher dimensions, are possible.

Determining Dependence Between Simulation Inputs

One of the design decisions for a Monte Carlo simulation is a choice of probability distributions for the random inputs. Selecting a distribution for each individual variable is often straightforward, but deciding what dependencies should exist between the inputs may not be. Ideally, input data to a simulation should reflect what you know about dependence among the real quantities you are modeling. However, there may be little or no information on which to base any dependence in the simulation. In such cases, it is useful to experiment with different possibilities in order to determine the model's sensitivity.

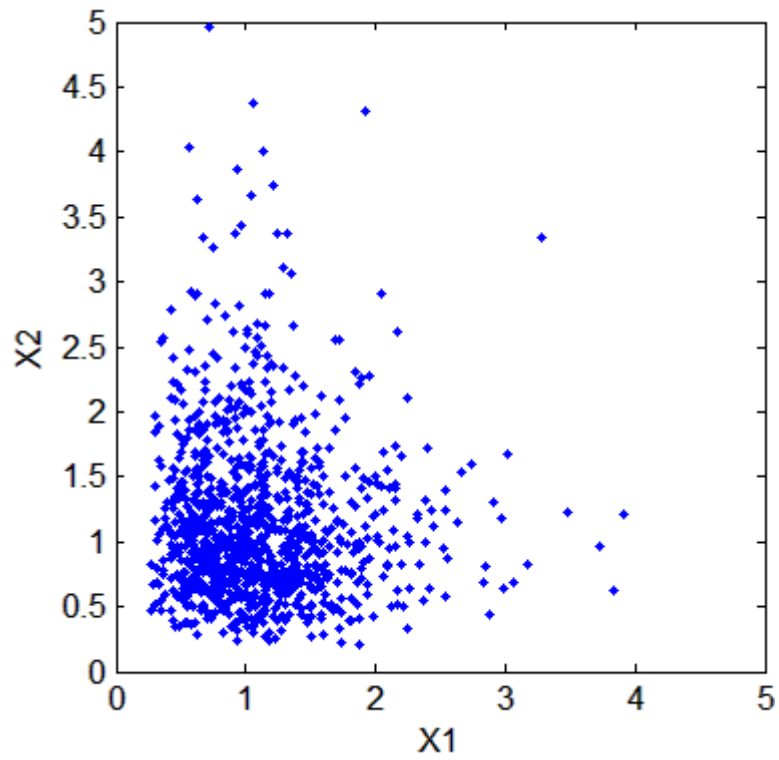
It can be difficult to generate random inputs with dependence when they have distributions that are not from a standard multivariate distribution. Further, some of the standard multivariate distributions can model only limited types of dependence. It is always possible to make the inputs independent, and while that is a simple choice, it is not always sensible and can lead to the wrong conclusions.

For example, a Monte-Carlo simulation of financial risk could have two random inputs that represent different sources of insurance losses. You could model these inputs as lognormal random variables. A reasonable question to ask is how dependence between these two inputs affects the results of the simulation. Indeed, you might know from real data that the same random conditions affect both sources; ignoring that in the simulation could lead to the wrong conclusions.

Example: Generate and Exponentiate Normal Random Variables.

The `lognrnd` function simulates independent lognormal random variables. In the following example, the `mvnrnd` function generates n pairs of independent normal random variables, and then exponentiates them. Notice that the covariance matrix used here is diagonal:

```
n = 1000;  
  
sigma = .5;  
SigmaInd = sigma.^2 .* [1 0; 0 1]  
SigmaInd =  
    0.25    0  
    0    0.25  
ZInd = mvnrnd([0 0],SigmaInd,n);  
XInd = exp(ZInd);  
  
plot(XInd(:,1),XInd(:,2),'.')  
axis([0 5 0 5])  
axis equal  
xlabel('X1')  
ylabel('X2')
```



Dependent bivariate lognormal random variables are also easy to generate using a covariance matrix with nonzero off-diagonal terms:

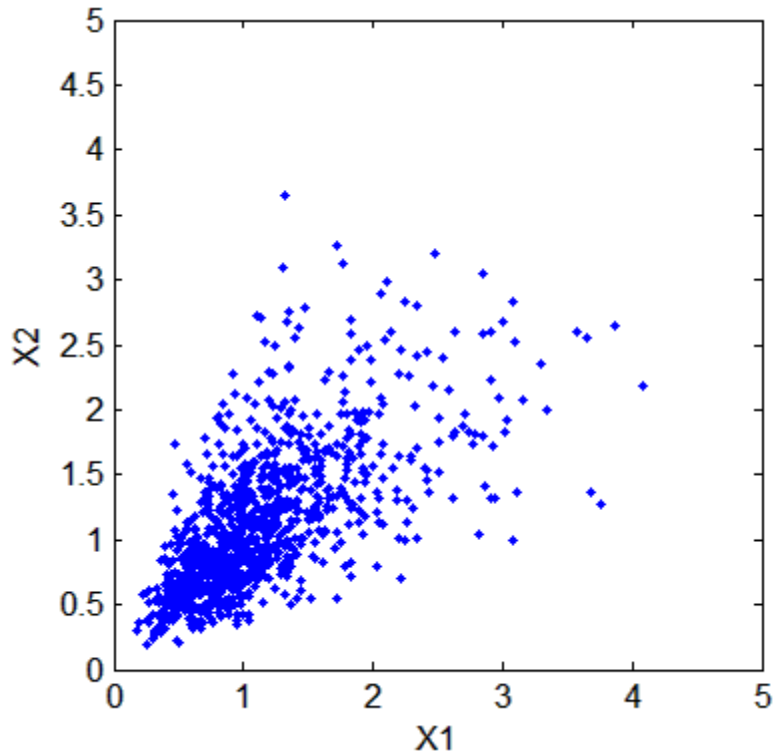
```
rho = .7;

SigmaDep = sigma.^2 .* [1 rho; rho 1]
SigmaDep =
    0.25    0.175
    0.175    0.25

ZDep = mvnrnd([0 0],SigmaDep,n);
XDep = exp(ZDep);
```

A second scatter plot demonstrates the difference between these two bivariate distributions:

```
plot(XDep(:,1),XDep(:,2),'.')
axis([0 5 0 5])
axis equal
xlabel('X1')
ylabel('X2')
```



It is clear that there is a tendency in the second data set for large values of X_1 to be associated with large values of X_2 , and similarly for small values. The correlation parameter, ρ , of the underlying bivariate normal determines this dependence. The conclusions drawn from the simulation could well depend on whether you generate X_1 and X_2 with dependence. The bivariate lognormal distribution is a simple solution in this case; it easily generalizes to higher dimensions in cases where the marginal distributions are different lognormals.

Other multivariate distributions also exist. For example, the multivariate t and the Dirichlet distributions simulate dependent t and beta random variables, respectively. But the list of simple multivariate distributions is not long, and they only apply in cases where the marginals are all in the same family (or even the exact same distributions). This can be a serious limitation in many situations.

Constructing Dependent Bivariate Distributions

Although the construction discussed in the previous section creates a bivariate lognormal that is simple, it serves to illustrate a method that is more generally applicable.

- 1 Generate pairs of values from a bivariate normal distribution. There is statistical dependence between these two variables, and each has a normal marginal distribution.
- 2 Apply a transformation (the exponential function) separately to each variable, changing the marginal distributions into lognormals. The transformed variables still have a statistical dependence.

If a suitable transformation can be found, this method can be generalized to create dependent bivariate random vectors with other marginal distributions. In fact, a general method of constructing such a transformation does exist, although it is not as simple as exponentiation alone.

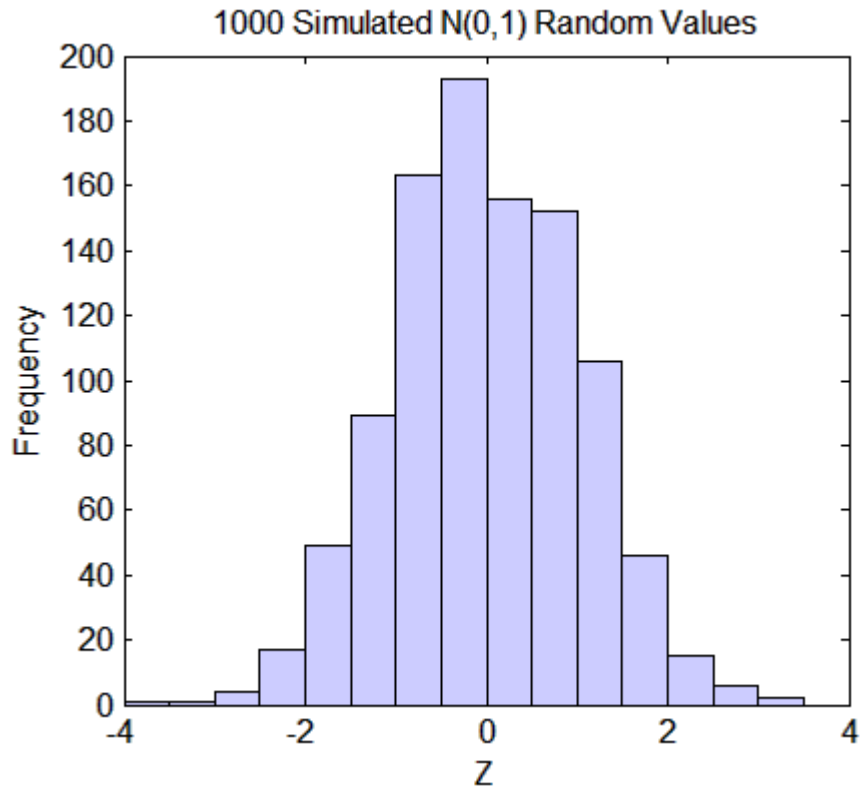
By definition, applying the normal cumulative distribution function (cdf), denoted here by Φ , to a standard normal random variable results in a random variable that is uniform on the interval $[0,1]$. To see this, if Z has a standard normal distribution, then the cdf of $U = \Phi(Z)$ is

$$\Pr\{U \leq u\} = \Pr\{\Phi(Z) \leq u\} = \Pr\{Z \leq \Phi^{-1}(u)\} = u$$

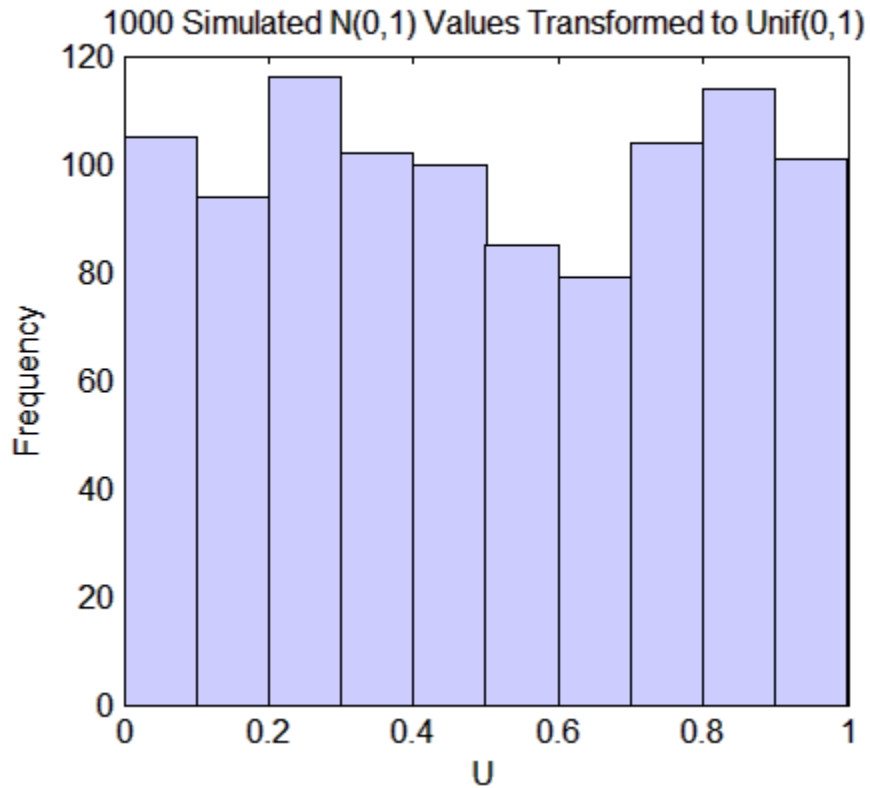
and that is the cdf of a $\text{Unif}(0,1)$ random variable. Histograms of some simulated normal and transformed values demonstrate that fact:

```
n = 1000;
z = normrnd(0,1,n,1);

hist(z,-3.75:.5:3.75)
xlim([-4 4])
title('1000 Simulated N(0,1) Random Values')
xlabel('Z')
ylabel('Frequency')
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
```



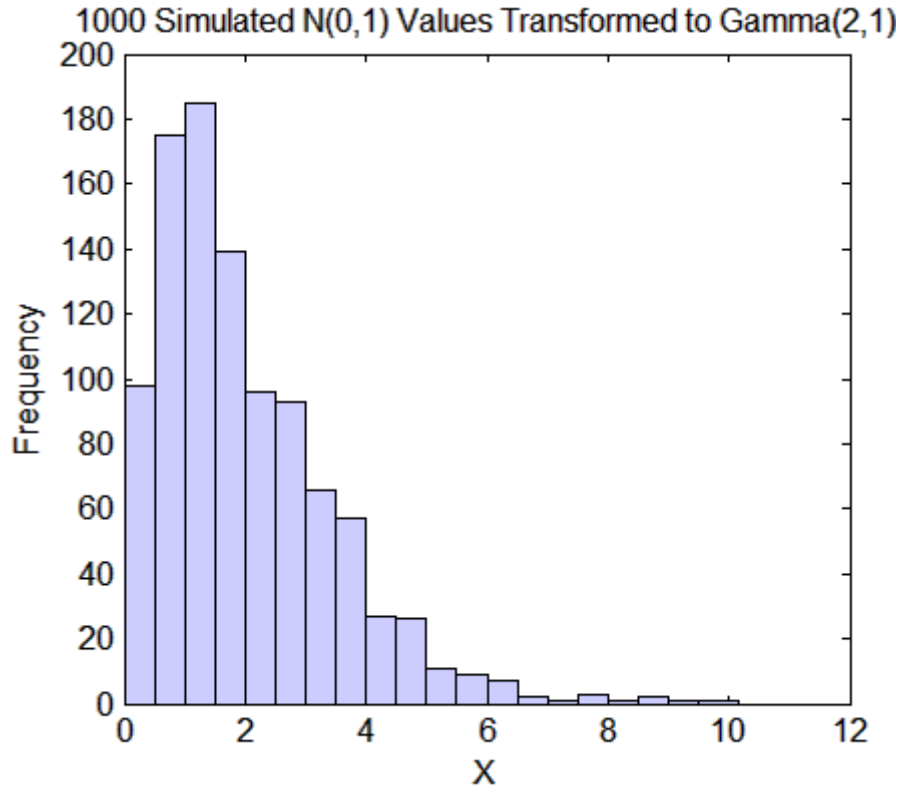
```
u = normcdf(z);  
  
hist(u,.05:.1:.95)  
title('1000 Simulated N(0,1) Values Transformed to Unif(0,1)')  
xlabel('U')  
ylabel('Frequency')  
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
```



Borrowing from the theory of univariate random number generation, applying the inverse cdf of any distribution, F , to a $\text{Unif}(0,1)$ random variable results in a random variable whose distribution is exactly F (see “Inversion Methods” on page 6-7). The proof is essentially the opposite of the preceding proof for the forward case. Another histogram illustrates the transformation to a gamma distribution:

```
x = gaminv(u,2,1);

hist(x,.25:.5:9.75)
title('1000 Simulated N(0,1) Values Transformed to Gamma(2,1)')
xlabel('X')
ylabel('Frequency')
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
```



You can apply this two-step transformation to each variable of a standard bivariate normal, creating dependent random variables with arbitrary marginal distributions. Because the transformation works on each component separately, the two resulting random variables need not even have the same marginal distributions. The transformation is defined as:

$$Z = [Z_1, Z_2] \square N\left([0,0], \begin{bmatrix} 1 & \rho \\ \rho & 1 \end{bmatrix}\right)$$

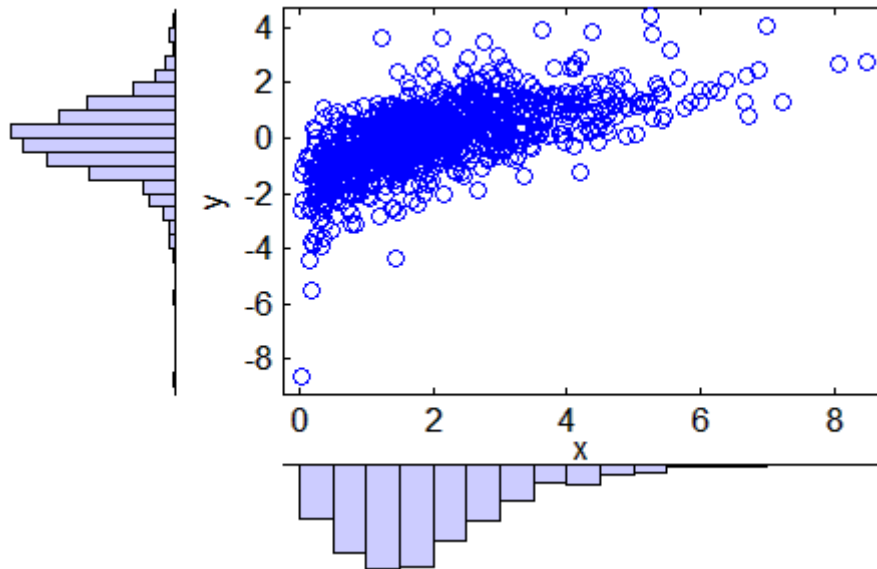
$$U = [\Phi(Z_1), \Phi(Z_2)]$$

$$X = [G_1(U_1), G_2(U_2)]$$

where G_1 and G_2 are inverse cdfs of two possibly different distributions. For example, the following generates random vectors from a bivariate distribution with t_5 and Gamma(2,1) marginals:

```
n = 1000; rho = .7;
Z = mvnrnd([0 0],[1 rho; rho 1],n);
U = normcdf(Z);
X = [gaminv(U(:,1),2,1) tinvs(U(:,2),5)];

scatterhist(X(:,1),X(:,2),'Direction','out')
```



This plot has histograms alongside a scatter plot to show both the marginal distributions, and the dependence.

Using Rank Correlation Coefficients

The correlation parameter, ρ , of the underlying bivariate normal determines the dependence between X_1 and X_2 in this construction. However, the linear correlation of X_1 and X_2 is not ρ . For example, in the original lognormal case, a closed form for that correlation is:

$$\text{cor}(X1, X2) = \frac{e^{\rho\sigma^2} - 1}{e^{\sigma^2} - 1}$$

which is strictly less than ρ , unless ρ is exactly 1. In more general cases such as the Gamma/ t construction, the linear correlation between $X1$ and $X2$ is difficult or impossible to express in terms of ρ , but simulations show that the same effect happens.

That is because the linear correlation coefficient expresses the linear dependence between random variables, and when nonlinear transformations are applied to those random variables, linear correlation is not preserved. Instead, a rank correlation coefficient, such as Kendall's τ or Spearman's ρ , is more appropriate.

Roughly speaking, these rank correlations measure the degree to which large or small values of one random variable associate with large or small values of another. However, unlike the linear correlation coefficient, they measure the association only in terms of ranks. As a consequence, the rank correlation is preserved under any monotonic transformation. In particular, the transformation method just described preserves the rank correlation. Therefore, knowing the rank correlation of the bivariate normal Z exactly determines the rank correlation of the final transformed random variables, X . While the linear correlation coefficient, ρ , is still needed to parameterize the underlying bivariate normal, Kendall's τ or Spearman's ρ are more useful in describing the dependence between random variables, because they are invariant to the choice of marginal distribution.

For the bivariate normal, there is a simple one-to-one mapping between Kendall's τ or Spearman's ρ , and the linear correlation coefficient ρ :

$$\begin{aligned} \tau &= \frac{2}{\pi} \arcsin(\rho) \quad \text{or} \quad \rho = \sin\left(\tau \frac{\pi}{2}\right) \\ \rho_s &= \frac{6}{\pi} \arcsin\left(\frac{\rho}{2}\right) \quad \text{or} \quad \rho = 2\sin\left(\rho_s \frac{\pi}{6}\right) \end{aligned}$$

The following plot shows the relationship:

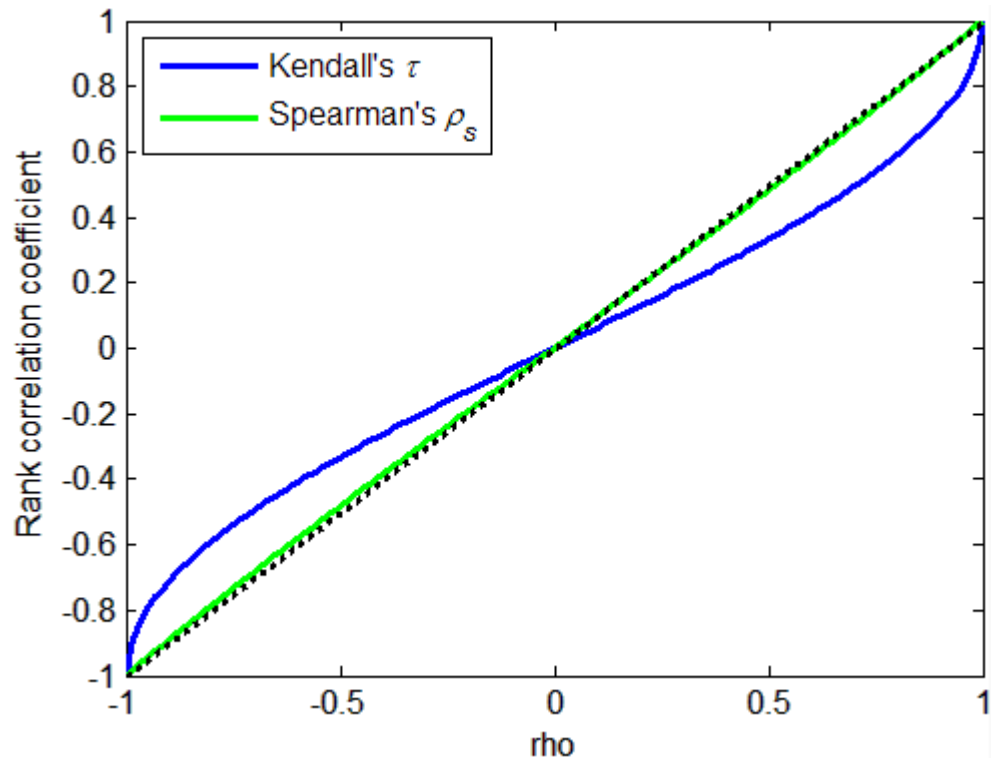
```
rho = -1:.01:1;
```

```

tau = 2.*asin(rho)./pi;
rho_s = 6.*asin(rho./2)./pi;

plot(rho,tau,'b-','LineWidth',2)
hold on
plot(rho,rho_s,'g-','LineWidth',2)
plot([-1 1],[-1 1],'k:','LineWidth',2)
axis([-1 1 -1 1])
xlabel('rho')
ylabel('Rank correlation coefficient')
legend('Kendall''s  $\tau$ ', ...
       'Spearman''s  $\rho_s$ ', ...
       'location','NW')

```



Thus, it is easy to create the desired rank correlation between X_1 and X_2 , regardless of their marginal distributions, by choosing the correct ρ parameter value for the linear correlation between Z_1 and Z_2 .

For the multivariate normal distribution, Spearman's rank correlation is almost identical to the linear correlation. However, this is not true once you transform to the final random variables.

Using Bivariate Copulas

The first step of the construction described in the previous section defines what is known as a bivariate Gaussian copula. A copula is a multivariate probability distribution, where each random variable has a uniform marginal distribution on the unit interval $[0,1]$. These variables may be completely independent, deterministically related (e.g., $U_2 = U_1$), or anything in between. Because of the possibility for dependence among variables, you can use a copula to construct a new multivariate distribution for dependent variables. By transforming each of the variables in the copula separately using the inversion method, possibly using different cdfs, the resulting distribution can have arbitrary marginal distributions. Such multivariate distributions are often useful in simulations, when you know that the different random inputs are not independent of each other.

Statistics Toolbox functions compute:

- Probability density functions (`copulapdf`) and the cumulative distribution functions (`copulacdf`) for Gaussian copulas
- Rank correlations from linear correlations (`copulastat`) and vice versa (`copulaparam`)
- Random vectors (`copularnd`)
- Parameters for copulas fit to data (`copulafit`)

For example, use the `copularnd` function to create scatter plots of random values from a bivariate Gaussian copula for various levels of ρ , to illustrate the range of different dependence structures. The family of bivariate Gaussian copulas is parameterized by the linear correlation matrix:

$$P = \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}$$

U1 and U2 approach linear dependence as ρ approaches ± 1 , and approach complete independence as ρ approaches zero:

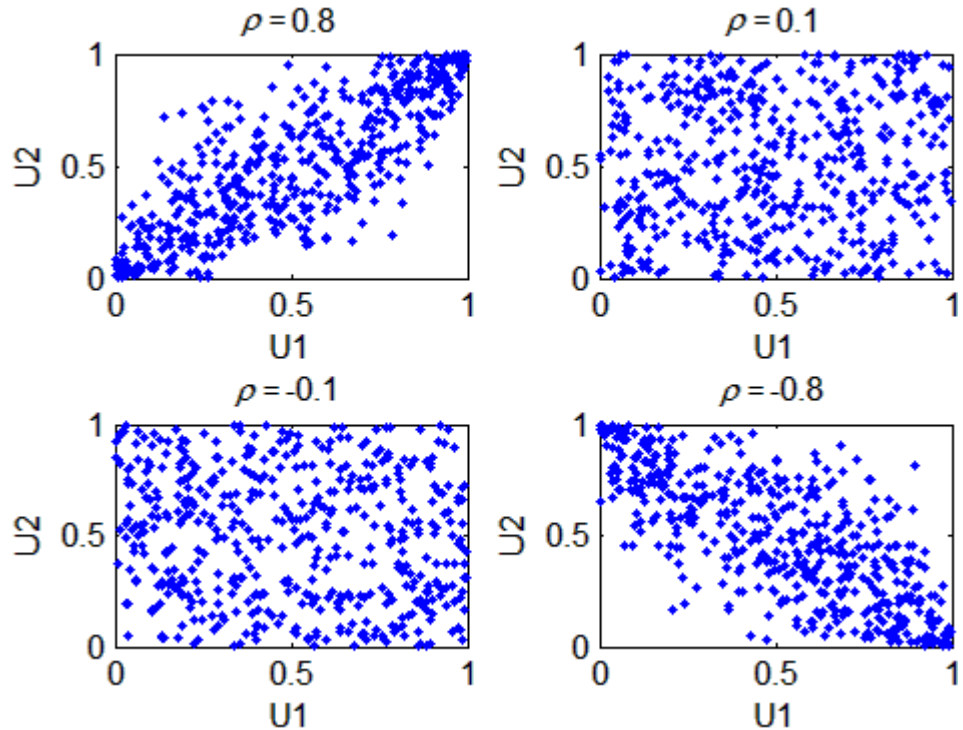
```
n = 500;
```

```
U = copularnd('Gaussian',[1 .8; .8 1],n);
subplot(2,2,1)
plot(U(:,1),U(:,2),'.')
title('\it\rho = 0.8')
xlabel('U1')
ylabel('U2')
```

```
U = copularnd('Gaussian',[1 .1; .1 1],n);
subplot(2,2,2)
plot(U(:,1),U(:,2),'.')
title('\it\rho = 0.1')
xlabel('U1')
ylabel('U2')
```

```
U = copularnd('Gaussian',[1 -.1; -.1 1],n);
subplot(2,2,3)
plot(U(:,1),U(:,2),'.')
title('\it\rho = -0.1')
xlabel('U1')
ylabel('U2')
```

```
U = copularnd('Gaussian',[1 -.8; -.8 1],n);
subplot(2,2,4)
plot(U(:,1),U(:,2),'.')
title('\it\rho = -0.8')
xlabel('U1')
ylabel('U2')
```



The dependence between U_1 and U_2 is completely separate from the marginal distributions of $X_1 = G(U_1)$ and $X_2 = G(U_2)$. X_1 and X_2 can be given any marginal distributions, and still have the same rank correlation. This is one of the main appeals of copulas—they allow this separate specification of dependence and marginal distribution. You can also compute the pdf (`copulapdf`) and the cdf (`copulacdf`) for a copula. For example, these plots show the pdf and cdf for $\rho = .8$:

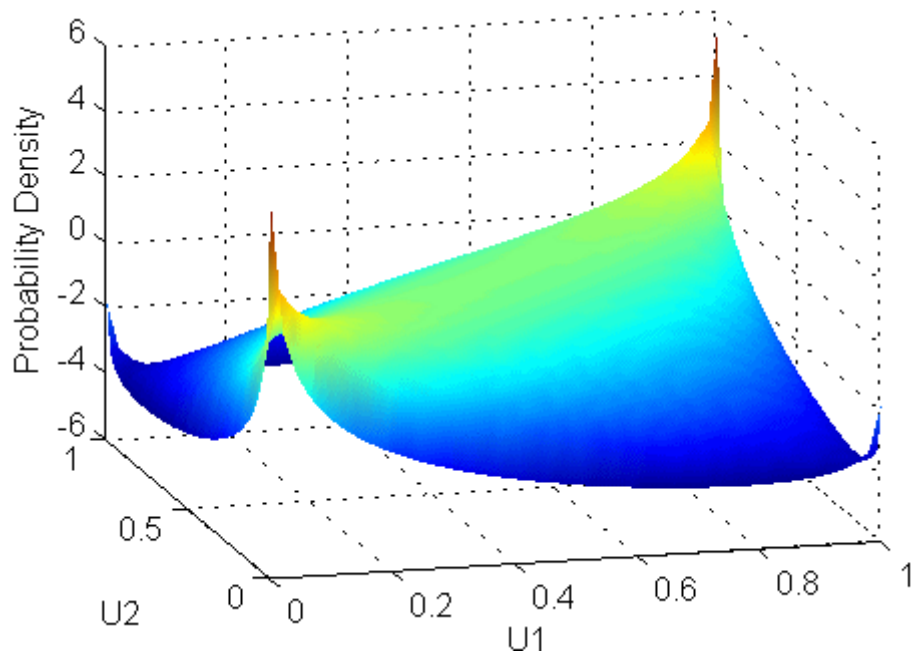
```
u1 = linspace(1e-3,1-1e-3,50);
u2 = linspace(1e-3,1-1e-3,50);
[U1,U2] = meshgrid(u1,u2);
Rho = [1 .8; .8 1];
f = copulapdf('t',[U1(:) U2(:)],Rho,5);
f = reshape(f,size(U1));

surf(u1,u2,log(f),'FaceColor','interp','EdgeColor','none')
```

```

view([-15,20])
xlabel('U1')
ylabel('U2')
zlabel('Probability Density')

```



```

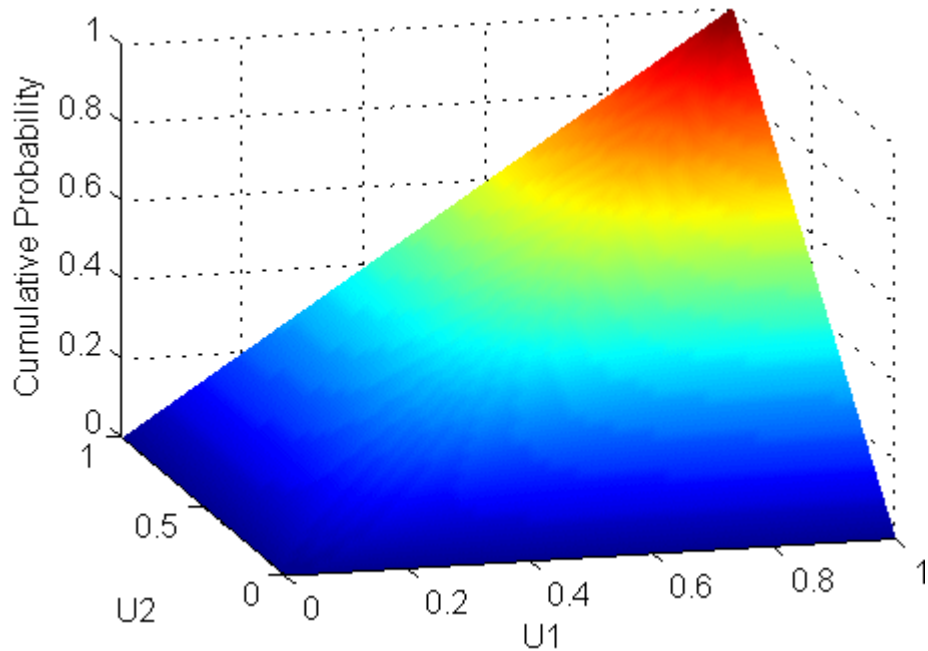
u1 = linspace(1e-3,1-1e-3,50);
u2 = linspace(1e-3,1-1e-3,50);
[U1,U2] = meshgrid(u1,u2);
F = copulacdf('t',[U1(:) U2(:)],Rho,5);
F = reshape(F,size(U1));

```

```

surf(u1,u2,F,'FaceColor','interp','EdgeColor','none')
view([-15,20])
xlabel('U1')
ylabel('U2')
zlabel('Cumulative Probability')

```



A different family of copulas can be constructed by starting from a bivariate t distribution and transforming using the corresponding t cdf. The bivariate t distribution is parameterized with P , the linear correlation matrix, and ν , the degrees of freedom. Thus, for example, you can speak of a t_1 or a t_5 copula, based on the multivariate t with one and five degrees of freedom, respectively.

Just as for Gaussian copulas, Statistics Toolbox functions for t copulas compute:

- Probability density functions (`copulapdf`) and the cumulative distribution functions (`copulacdf`) for Gaussian copulas
- Rank correlations from linear correlations (`copulastat`) and vice versa (`copulaparam`)
- Random vectors (`copularnd`)
- Parameters for copulas fit to data (`copulafit`)

For example, use the `copularnd` function to create scatter plots of random values from a bivariate t_1 copula for various levels of ρ , to illustrate the range of different dependence structures:

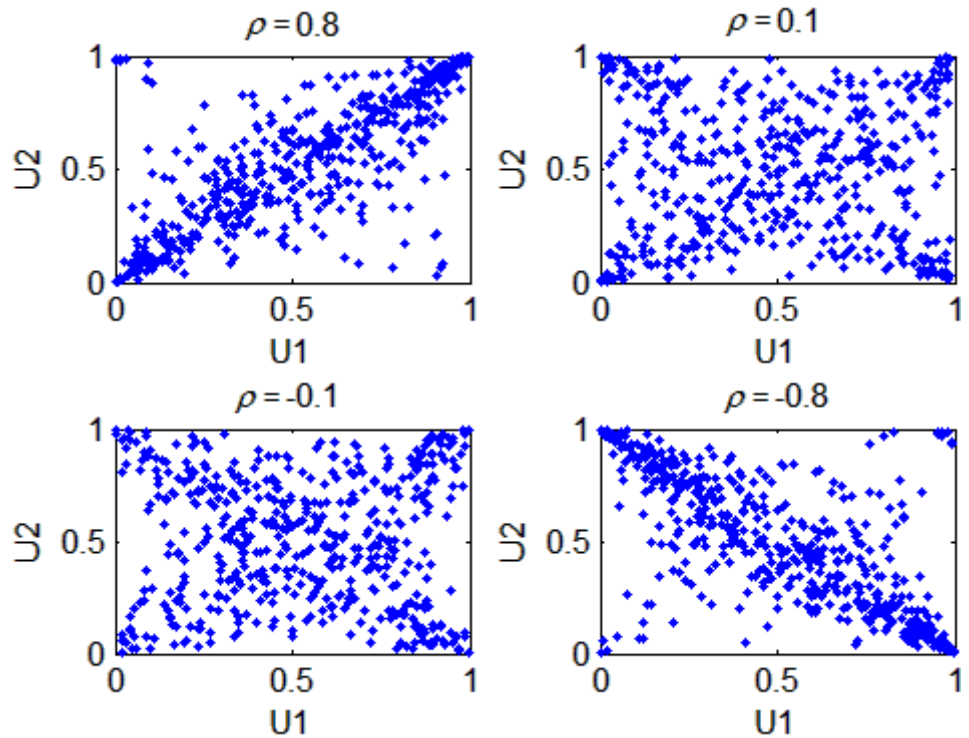
```
n = 500;
nu = 1;

U = copularnd('t',[1 .8; .8 1],nu,n);
subplot(2,2,1)
plot(U(:,1),U(:,2),'.')
title('\it\rho = 0.8')
xlabel('U1')
ylabel('U2')

U = copularnd('t',[1 .1; .1 1],nu,n);
subplot(2,2,2)
plot(U(:,1),U(:,2),'.')
title('\it\rho = 0.1')
xlabel('U1')
ylabel('U2')

U = copularnd('t',[1 -.1; -.1 1],nu,n);
subplot(2,2,3)
plot(U(:,1),U(:,2),'.')
title('\it\rho = -0.1')
xlabel('U1')
ylabel('U2')

U = copularnd('t',[1 -.8; -.8 1],nu, n);
subplot(2,2,4)
plot(U(:,1),U(:,2),'.')
title('\it\rho = -0.8')
xlabel('U1')
ylabel('U2')
```



A t copula has uniform marginal distributions for U_1 and U_2 , just as a Gaussian copula does. The rank correlation τ or ρ_s between components in a t copula is also the same function of ρ as for a Gaussian. However, as these plots demonstrate, a t_1 copula differs quite a bit from a Gaussian copula, even when their components have the same rank correlation. The difference is in their dependence structure. Not surprisingly, as the degrees of freedom parameter ν is made larger, a t_ν copula approaches the corresponding Gaussian copula.

As with a Gaussian copula, any marginal distributions can be imposed over a t copula. For example, using a t copula with 1 degree of freedom, you can again generate random vectors from a bivariate distribution with $\text{Gamma}(2,1)$ and t_5 marginals using `copularnd`:

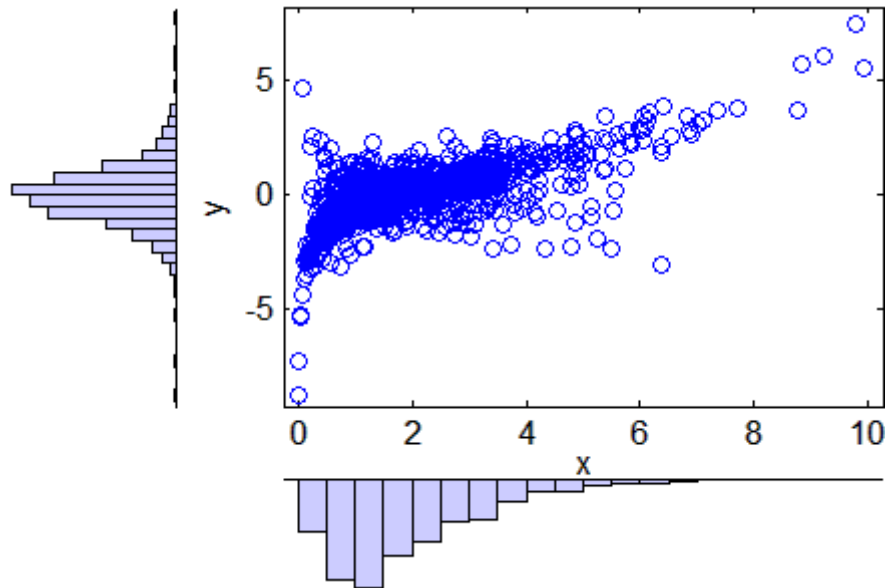
```
n = 1000;
rho = .7;
nu = 1;
```

```

U = copularnd('t',[1 rho; rho 1],nu,n);
X = [gaminv(U(:,1),2,1) tinv(U(:,2),5)];

scatterhist(X(:,1),X(:,2),'Direction','out')

```



Compared to the bivariate Gamma/ t distribution constructed earlier, which was based on a Gaussian copula, the distribution constructed here, based on a t_1 copula, has the same marginal distributions and the same rank correlation between variables but a very different dependence structure. This illustrates the fact that multivariate distributions are not uniquely defined by their marginal distributions, or by their correlations. The choice of a particular copula in an application may be based on actual observed data, or different copulas may be used as a way of determining the sensitivity of simulation results to the input distribution.

Higher Dimension Copulas

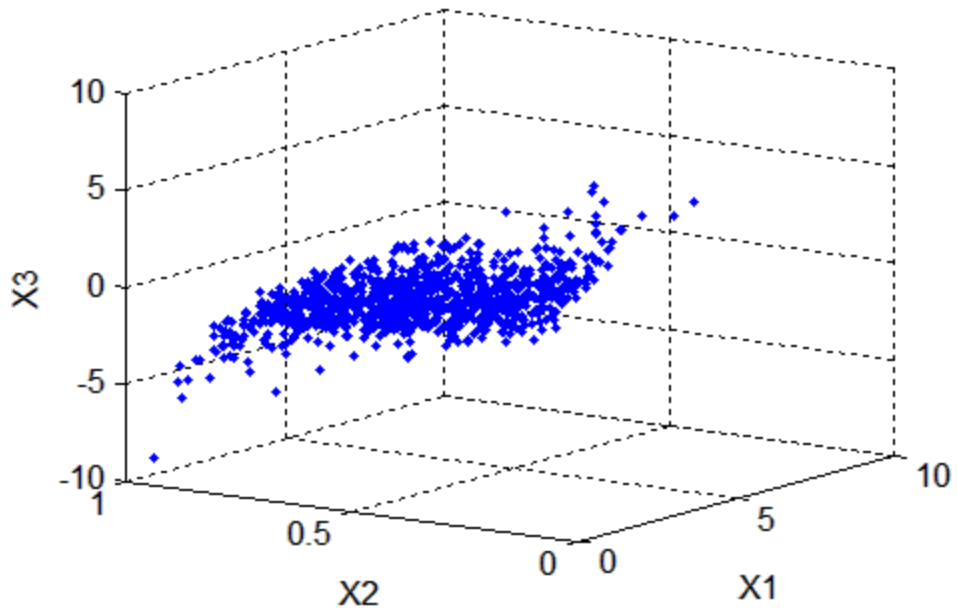
The Gaussian and t copulas are known as elliptical copulas. It is easy to generalize elliptical copulas to a higher number of dimensions. For example, simulate data from a trivariate distribution with Gamma(2,1), Beta(2,2), and t_5 marginals using a Gaussian copula and `copularnd`, as follows:

```

n = 1000;
Rho = [1 .4 .2; .4 1 -.8; .2 -.8 1];
U = copularnd('Gaussian',Rho,n);
X = [gaminv(U(:,1),2,1) betainv(U(:,2),2,2) tinv(U(:,3),5)];

subplot(1,1,1)
plot3(X(:,1),X(:,2),X(:,3),'.')
grid on
view([-55, 15])
xlabel('X1')
ylabel('X2')
zlabel('X3')

```



Notice that the relationship between the linear correlation parameter ρ and, for example, Kendall's τ , holds for each entry in the correlation matrix P used here. You can verify that the sample rank correlations of the data are approximately equal to the theoretical values:

```

tauTheoretical = 2.*asin(Rho)./pi
tauTheoretical =

```



```

      1      0.26198      0.12819
0.26198      1      -0.59033
0.12819     -0.59033      1

```

```
tauSample = corr(X, 'type', 'Kendall')
```

```
tauSample =
      1      0.27254      0.12701
0.27254      1      -0.58182
0.12701     -0.58182      1

```

Archimedean Copulas

Statistics Toolbox functions are available for three bivariate Archimedean copula families:

- Clayton copulas
- Frank copulas
- Gumbel copulas

These are one-parameter families that are defined directly in terms of their cdfs, rather than being defined constructively using a standard multivariate distribution.

To compare these three Archimedean copulas to the Gaussian and t bivariate copulas, first use the `copulastat` function to find the rank correlation for a Gaussian or t copula with linear correlation parameter of 0.8, and then use the `copulaparam` function to find the Clayton copula parameter that corresponds to that rank correlation:

```
tau = copulastat('Gaussian', .8, 'type', 'kendall')
tau =
    0.59033

```

```
alpha = copulaparam('Clayton', tau, 'type', 'kendall')
alpha =
    2.882

```

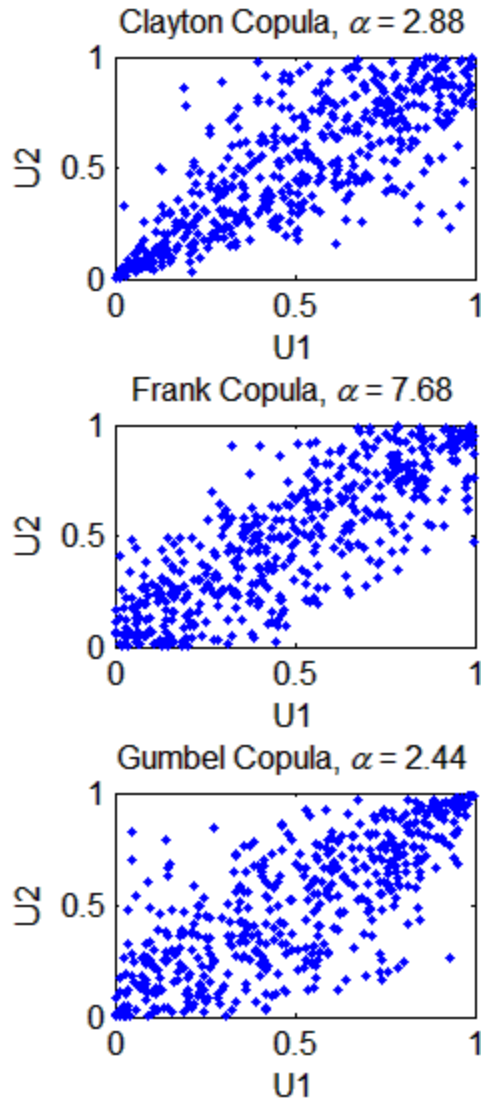
Finally, plot a random sample from the Clayton copula with `copularnd`. Repeat the same procedure for the Frank and Gumbel copulas:

```
n = 500;

U = copularnd('Clayton',alpha,n);
subplot(3,1,1)
plot(U(:,1),U(:,2),'.');
title(['Clayton Copula, {\it\alpha} = ',sprintf('%0.2f',alpha)])
xlabel('U1')
ylabel('U2')

alpha = copulaparam('Frank',tau,'type','kendall');
U = copularnd('Frank',alpha,n);
subplot(3,1,2)
plot(U(:,1),U(:,2),'.');
title(['Frank Copula, {\it\alpha} = ',sprintf('%0.2f',alpha)])
xlabel('U1')
ylabel('U2')

alpha = copulaparam('Gumbel',tau,'type','kendall');
U = copularnd('Gumbel',alpha,n);
subplot(3,1,3)
plot(U(:,1),U(:,2),'.');
title(['Gumbel Copula, {\it\alpha} = ',sprintf('%0.2f',alpha)])
xlabel('U1')
ylabel('U2')
```



Simulating Dependent Multivariate Data Using Copulas

To simulate dependent multivariate data using a copula, you must specify each of the following:

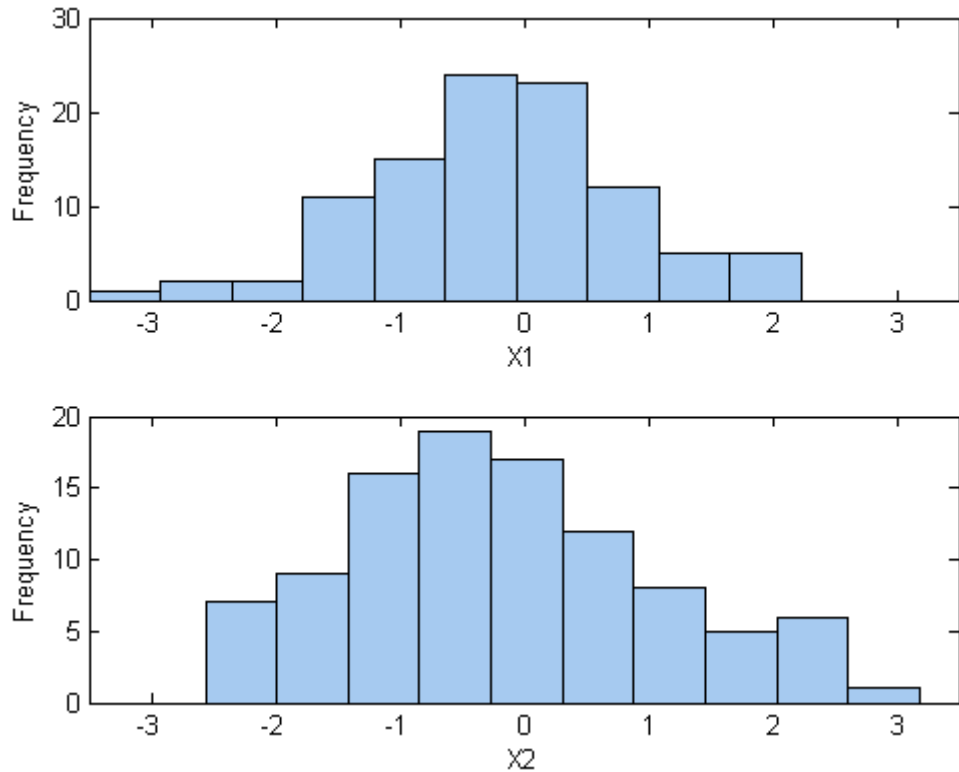
- The copula family (and any shape parameters)
- The rank correlations among variables
- Marginal distributions for each variable

Suppose you have return data for two stocks and want to run a Monte Carlo simulation with inputs that follow the same distributions as the data:

```
load stockreturns
nobs = size(stocks,1);

subplot(2,1,1)
hist(stocks(:,1),10)
xlim([-3.5 3.5])
xlabel('X1')
ylabel('Frequency')
set(get(gca,'Children'),'FaceColor',[.8 .8 1])

subplot(2,1,2)
hist(stocks(:,2),10)
xlim([-3.5 3.5])
xlabel('X2')
ylabel('Frequency')
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
```



You could fit a parametric model separately to each dataset, and use those estimates as the marginal distributions. However, a parametric model may not be sufficiently flexible. Instead, you can use a nonparametric model to transform to the marginal distributions. All that is needed is a way to compute the inverse cdf for the nonparametric model.

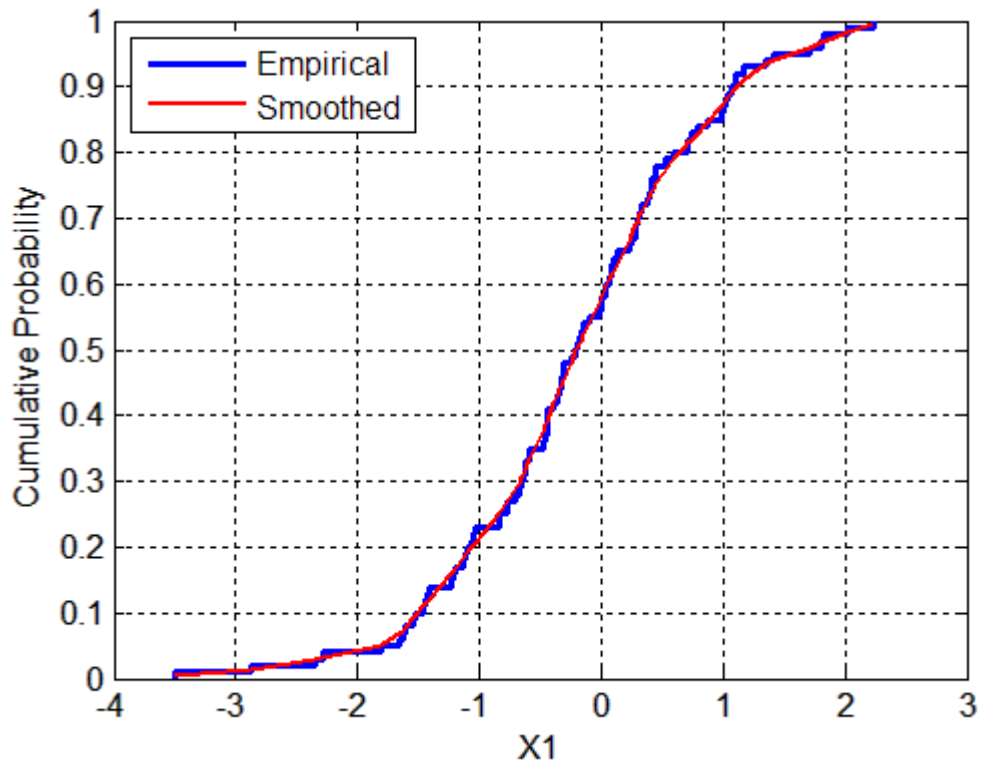
The simplest nonparametric model is the empirical cdf, as computed by the `ecdf` function. For a discrete marginal distribution, this is appropriate. However, for a continuous distribution, use a model that is smoother than the step function computed by `ecdf`. One way to do that is to estimate the empirical cdf and interpolate between the midpoints of the steps with a piecewise linear function. Another way is to use kernel smoothing with `ksdensity`. For example, compare the empirical cdf to a kernel smoothed cdf estimate for the first variable:

```
[Fi,xi] = ecdf(stocks(:,1));

stairs(xi,Fi,'b','LineWidth',2)
hold on

Fi_sm = ksdensity(stocks(:,1),xi,'function','cdf','width',.15);

plot(xi,Fi_sm,'r-','LineWidth',1.5)
xlabel('X1')
ylabel('Cumulative Probability')
legend('Empirical','Smoothed','Location','NW')
grid on
```



For the simulation, experiment with different copulas and correlations. Here, you will use a bivariate t copula with a fairly small degrees of freedom

parameter. For the correlation parameter, you can compute the rank correlation of the data, and then find the corresponding linear correlation parameter for the t copula using `copulaparam`:

```
nu = 5;

tau = corr(stocks(:,1),stocks(:,2),'type','kendall')
tau =
    0.51798

rho = copulaparam('t', tau, nu, 'type','kendall')
rho =
    0.72679
```

Next, use `copularnd` to generate random values from the t copula and transform using the nonparametric inverse cdfs. The `ksdensity` function allows you to make a kernel estimate of distribution and evaluate the inverse cdf at the copula points all in one step:

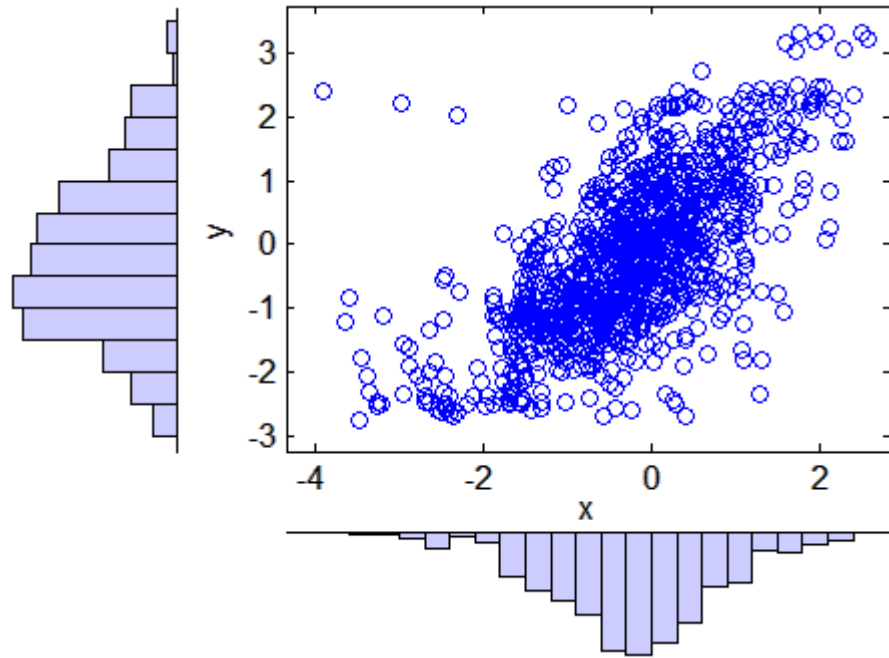
```
n = 1000;

U = copularnd('t',[1 rho; rho 1],nu,n);
X1 = ksdensity(stocks(:,1),U(:,1),...
    'function','icdf','width',.15);
X2 = ksdensity(stocks(:,2),U(:,2),...
    'function','icdf','width',.15);
```

Alternatively, when you have a large amount of data or need to simulate more than one set of values, it may be more efficient to compute the inverse cdf over a grid of values in the interval (0,1) and use interpolation to evaluate it at the copula points:

```
p = linspace(0.00001,0.99999,1000);
G1 = ksdensity(stocks(:,1),p,'function','icdf','width',0.15);
X1 = interp1(p,G1,U(:,1),'spline');
G2 = ksdensity(stocks(:,2),p,'function','icdf','width',0.15);
X2 = interp1(p,G2,U(:,2),'spline');

scatterhist(X1,X2,'Direction','out')
```



The marginal histograms of the simulated data are a smoothed version of the histograms for the original data. The amount of smoothing is controlled by the bandwidth input to `ksdensity`.

Example: Fitting Copulas to Data

The `copulafit` function is used to calibrate copulas with data. To generate data X_{sim} with a distribution “just like” (in terms of marginal distributions and correlations) the distribution of data in the matrix X :

- 1 Fit marginal distributions to the columns of X .
- 2 Use appropriate cdf functions to transform X to U , so that U has values between 0 and 1.
- 3 Use `copulafit` to fit a copula to U .
- 4 Generate new data U_{sim} from the copula.

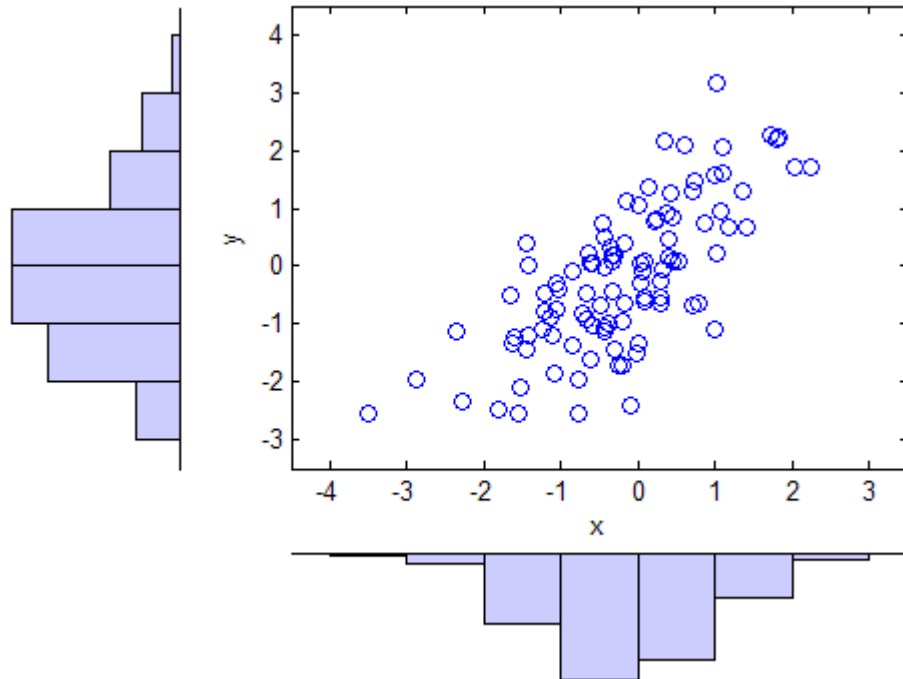
5 Use appropriate inverse cdf functions to transform U_{sim} to X_{sim} .

The following example illustrates the procedure.

Load and plot simulated stock return data:

```
load stockreturns
x = stocks(:,1);
y = stocks(:,2);

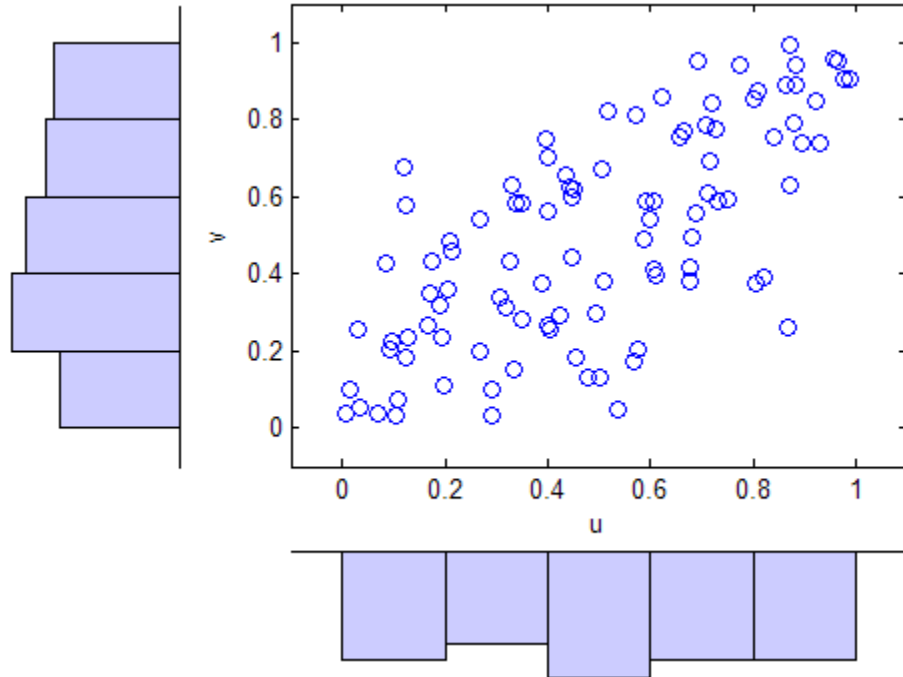
scatterhist(x,y,'Direction','out')
```



Transform the data to the copula scale (unit square) using a kernel estimator of the cumulative distribution function:

```
u = ksdensity(x,x,'function','cdf');
v = ksdensity(y,y,'function','cdf');
```

```
scatterhist(u,v,'Direction','out')
xlabel('u')
ylabel('v')
```



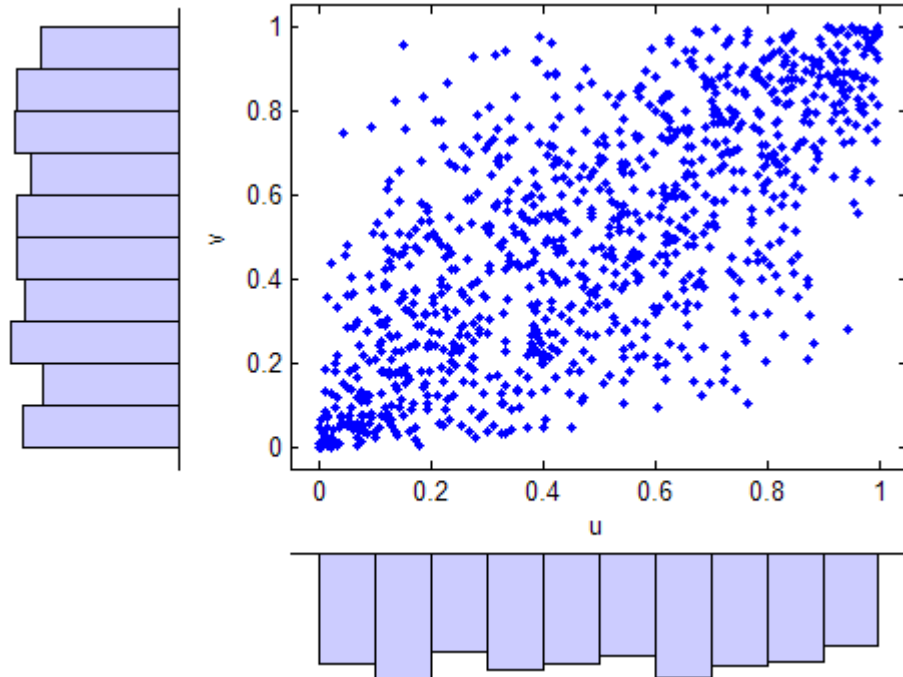
Fit a t copula:

```
[Rho,nu] = copulafit('t',[u v],'Method','ApproximateML')
Rho =
    1.0000    0.7220
    0.7220    1.0000
nu =
    3.2017e+006
```

Generate a random sample from the t copula:

```
r = copularnd('t',Rho,nu,1000);
u1 = r(:,1);
v1 = r(:,2);
```

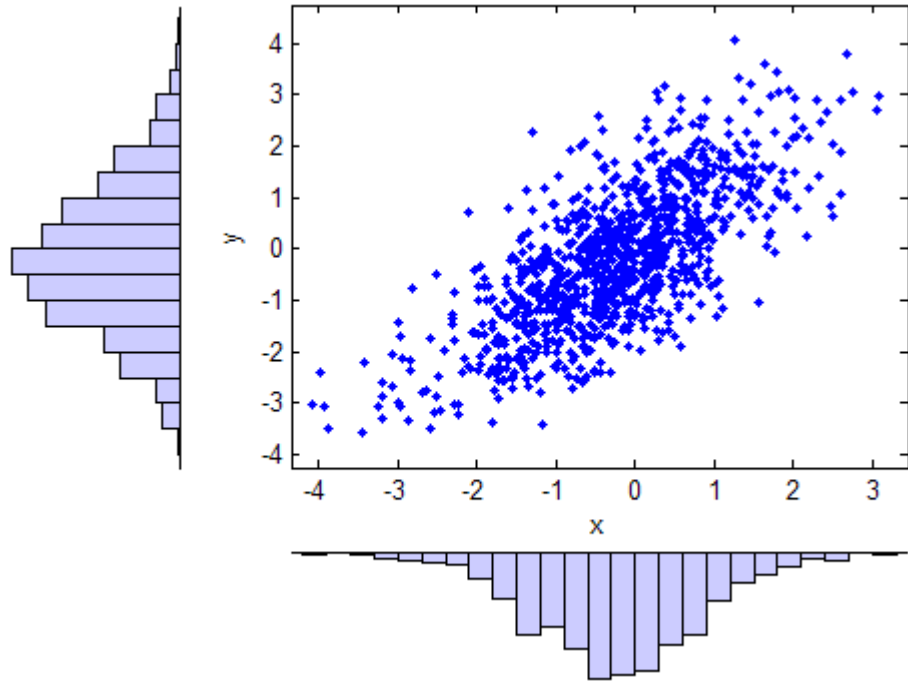
```
scatterhist(u1,v1,'Direction','out')
xlabel('u')
ylabel('v')
set(get(gca,'children'),'marker','.'))
```



Transform the random sample back to the original scale of the data:

```
x1 = ksdensity(x,u1,'function','icdf');
y1 = ksdensity(y,v1,'function','icdf');

scatterhist(x1,y1,'Direction','out')
set(get(gca,'children'),'marker','.'))
```



As the example illustrates, copulas integrate naturally with other distribution fitting functions.

Random Number Generation

- “Generating Random Data” on page 6-2
- “Random Number Generation Functions” on page 6-3
- “Common Generation Methods” on page 6-5
- “Representing Sampling Distributions Using Markov Chain Samplers” on page 6-13
- “Generating Quasi-Random Numbers” on page 6-15
- “Generating Data Using Flexible Families of Distributions” on page 6-25

Generating Random Data

Pseudorandom numbers are generated by deterministic algorithms. They are "random" in the sense that, on average, they pass statistical tests regarding their distribution and correlation. They differ from true random numbers in that they are generated by an algorithm, rather than a truly random process.

Random number generators (RNGs) like those in MATLAB are algorithms for generating pseudorandom numbers with a specified distribution.

For more information on random number generators for supported distributions, see "Random Number Generators" on page 5-81.

For more information on the GUI for generating random numbers from supported distributions, see "Visually Exploring Random Number Generation" on page 5-50.

Random Number Generation Functions

The following table lists the supported distributions and their respective random number generation functions. For more information on other functions for each distribution, see “Supported Distributions” on page 5-3. For more information on random number generators, see “Random Number Generators” on page 5-81.

Distribution	Random Number Generation Function
Beta	betarnd, random, randtool
Binomial	binornd, random, randtool
Chi-square	chi2rnd, random, randtool
Clayton copula	copularnd
Exponential	exprnd, random, randtool
Extreme value	evrnd, random, randtool
F	frnd, random, randtool
Frank copula	copularnd
Gamma	gamrnd, randg, random, randtool
Gaussian copula	copularnd
Gaussian mixture	random
Generalized extreme value	gevrnd, random, randtool
Generalized Pareto	gprnd, random, randtool
Geometric	geornd, random, randtool
Gumbel copula	copularnd
Hypergeometric	hygernd, random
Inverse Wishart	iwishrnd
Johnson system	johnsrnd
Lognormal	lognrnd, random, randtool
Multinomial	mnrnd

Distribution	Random Number Generation Function
Multivariate normal	mvnrnd
Multivariate t	mvtrnd
Negative binomial	nbinrnd, random, randtool
Noncentral chi-square	ncx2rnd, random, randtool
Noncentral F	ncfrnd, random, randtool
Noncentral t	nctrnd, random, randtool
Normal (Gaussian)	normrnd, randn, random, randtool
Pearson system	pearsrnd
Piecewise	random
Poisson	poissrnd, random, randtool
Rayleigh	raylrnd, random, randtool
Student's t	trnd, random, randtool
t copula	copularnd
Uniform (continuous)	unifrnd, rand, random
Uniform (discrete)	unidrnd, random, randtool
Weibull	wblrnd, random
Wishart	wishrnd

Common Generation Methods

In this section...

“Direct Methods” on page 6-5

“Inversion Methods” on page 6-7

“Acceptance-Rejection Methods” on page 6-9

Methods for generating pseudorandom numbers usually start with uniform random numbers, like the MATLAB `rand` function produces. The methods described in this section detail how to produce random numbers from other distributions.

Direct Methods

Direct methods directly use the definition of the distribution.

For example, consider binomial random numbers. A binomial random number is the number of heads in N tosses of a coin with probability p of a heads on any single toss. If you generate N uniform random numbers on the interval $(0,1)$ and count the number less than p , then the count is a binomial random number with parameters N and p .

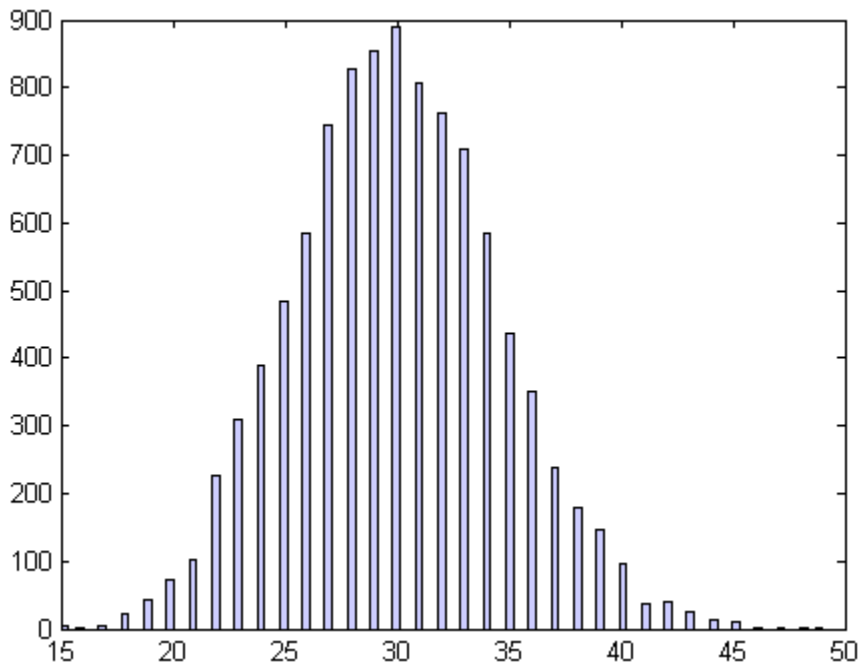
This function is a simple implementation of a binomial RNG using the direct approach:

```
function X = directbinornd(N,p,m,n)

X = zeros(m,n); % Preallocate memory
for i = 1:m*n
    u = rand(N,1);
    X(i) = sum(u < p);
end
```

For example:

```
X = directbinornd(100,0.3,1e4,1);
hist(X,101)
set(get(gca, 'Children'), 'FaceColor', [.8 .8 1])
```



The Statistics Toolbox function `binornd` uses a modified direct method, based on the definition of a binomial random variable as the sum of Bernoulli random variables.

You can easily convert the previous method to a random number generator for the Poisson distribution with parameter λ . The Poisson distribution is the limiting case of the binomial distribution as N approaches infinity, p approaches zero, and Np is held fixed at λ . To generate Poisson random numbers, create a version of the previous generator that inputs λ rather than N and p , and internally sets N to some large number and p to λ/N .

The Statistics Toolbox function `poissrnd` actually uses two direct methods:

- A waiting time method for small values of λ
- A method due to Ahrens and Dieter for larger values of λ

Inversion Methods

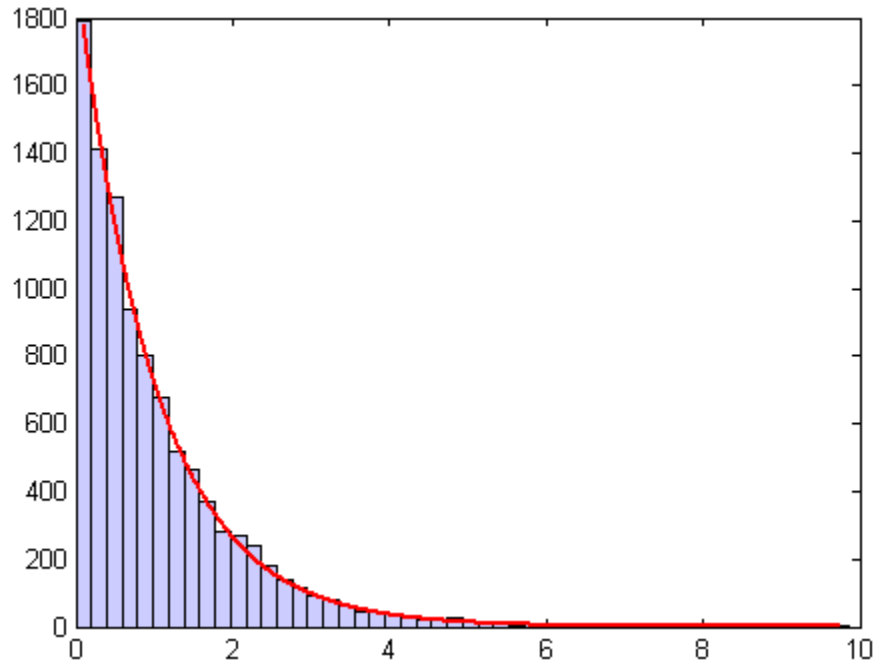
Inversion methods are based on the observation that continuous cumulative distribution functions (cdfs) range uniformly over the interval (0,1). If u is a uniform random number on (0,1), then using $X = F^{-1}(U)$ generates a random number X from a continuous distribution with specified cdf F .

For example, the following code generates random numbers from a specific exponential distribution using the inverse cdf and the MATLAB uniform random number generator `rand`:

```
mu = 1;  
X = expinv(rand(1e4,1),mu);
```

Compare the distribution of the generated random numbers to the pdf of the specified exponential by scaling the pdf to the area of the histogram used to display the distribution:

```
numbins = 50;  
hist(X,numbins)  
set(get(gca,'Children'),'FaceColor',[.8 .8 1])  
hold on  
  
[bincounts,binpositions] = hist(X,numbins);  
binwidth = binpositions(2) - binpositions(1);  
histarea = binwidth*sum(bincounts);  
  
x = binpositions(1):0.001:binpositions(end);  
y = exppdf(x,mu);  
plot(x,histarea*y,'r','LineWidth',2)
```



Inversion methods also work for discrete distributions. To generate a random number X from a discrete distribution with probability mass vector $P(X=x_i) = p_i$ where $x_0 < x_1 < x_2 < \dots$, generate a uniform random number u on $(0,1)$ and then set $X = x_i$ if $F(x_{i-1}) < u < F(x_i)$.

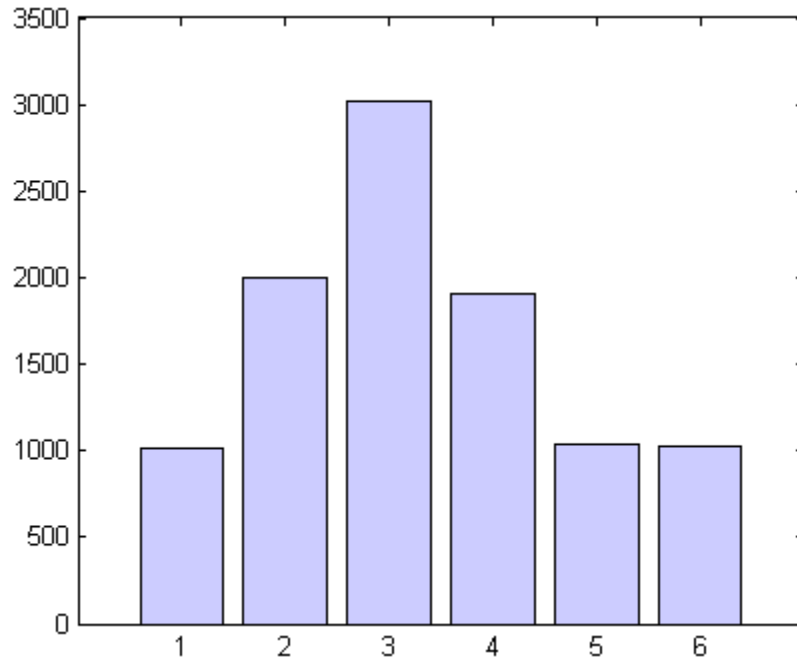
For example, the following function implements an inversion method for a discrete distribution with probability mass vector p :

```
function X = discreteinvrnd(p,m,n)

X = zeros(m,n); % Preallocate memory
for i = 1:m*n
    u = rand;
    I = find(u < cumsum(p));
    X(i) = min(I);
end
```

Use the function to generate random numbers from any discrete distribution:

```
p = [0.1 0.2 0.3 0.2 0.1 0.1]; % Probability mass vector
X = discreteinvrnd(p,1e4,1);
[n,x] = hist(X,length(p));
bar(1:length(p),n)
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
```

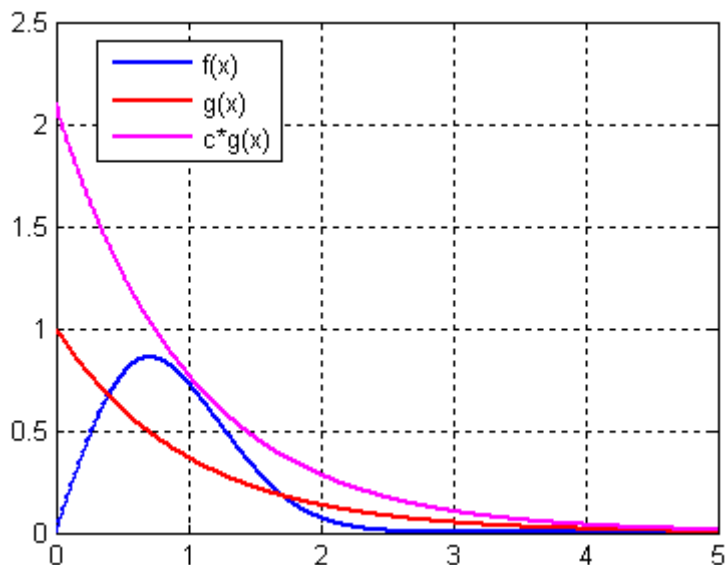


Acceptance-Rejection Methods

The functional form of some distributions makes it difficult or time-consuming to generate random numbers using direct or inversion methods.

Acceptance-rejection methods provide an alternative in these cases.

Acceptance-rejection methods begin with uniform random numbers, but require an additional random number generator. If your goal is to generate a random number from a continuous distribution with pdf f , acceptance-rejection methods first generate a random number from a continuous distribution with pdf g satisfying $f(x) \leq cg(x)$ for some c and all x .



A continuous acceptance-rejection RNG proceeds as follows:

- 1** Chooses a density g .
- 2** Finds a constant c such that $f(x)/g(x) \leq c$ for all x .
- 3** Generates a uniform random number u .
- 4** Generates a random number v from g .
- 5** If $cu \leq f(v)/g(v)$, accepts and returns v .
- 6** Otherwise, rejects v and goes to step 3.

For efficiency, a “cheap” method is necessary for generating random numbers from g , and the scalar c should be small. The expected number of iterations to produce a single random number is c .

The following function implements an acceptance-rejection method for generating random numbers from pdf f , given f , g , the RNG `grnd` for g , and the constant c :

```

function X = accrejrnd(f,g,grnd,c,m,n)

X = zeros(m,n); % Preallocate memory
for i = 1:m*n
    accept = false;
    while accept == false
        u = rand();
        v = grnd();
        if c*u <= f(v)/g(v)
            X(i) = v;
            accept = true;
        end
    end
end
end

```

For example, the function $f(x) = xe^{-x/2}$ satisfies the conditions for a pdf on $[0, \infty)$ (nonnegative and integrates to 1). The exponential pdf with mean 1, $f(x) = e^{-x}$, dominates g for c greater than about 2.2. Thus, you can use `rand` and `exprnd` to generate random numbers from f :

```

f = @(x)x.*exp(-(x.^2)/2);
g = @(x)exp(-x);
grnd = @()exprnd(1);
X = accrejrnd(f,g,grnd,2.2,1e4,1);

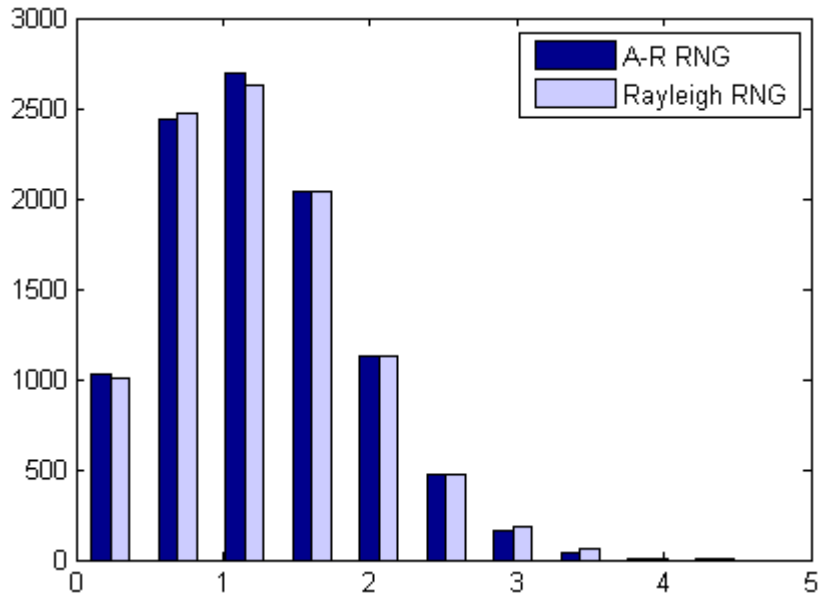
```

The pdf f is actually a Rayleigh distribution with shape parameter 1. This example compares the distribution of random numbers generated by the acceptance-rejection method with those generated by `raylrnd`:

```

Y = raylrnd(1,1e4,1);
hist([X Y])
h = get(gca,'Children');
set(h(1),'FaceColor',[.8 .8 1])
legend('A-R RNG','Rayleigh RNG')

```



The Statistics Toolbox function `raylrnd` uses a transformation method, expressing a Rayleigh random variable in terms of a chi-square random variable, which you compute using `randn`.

Acceptance-rejection methods also work for discrete distributions. In this case, the goal is to generate random numbers from a distribution with probability mass $P_p(X = i) = p_i$, assuming that you have a method for generating random numbers from a distribution with probability mass $P_q(X = i) = q_i$. The RNG proceeds as follows:

- 1** Chooses a density P_q .
- 2** Finds a constant c such that $p_i/q_i \leq c$ for all i .
- 3** Generates a uniform random number u .
- 4** Generates a random number v from P_q .
- 5** If $cu \leq p_i/q_i$, accepts and returns v .
- 6** Otherwise, rejects v and goes to step 3.

Representing Sampling Distributions Using Markov Chain Samplers

In this section...

“Using the Metropolis-Hastings Algorithm” on page 6-13

“Using Slice Sampling” on page 6-14

The methods in “Common Generation Methods” on page 6-5 might be inadequate when sampling distributions are difficult to represent in computations. Such distributions arise, for example, in Bayesian data analysis and in the large combinatorial problems of Markov chain Monte Carlo (MCMC) simulations. An alternative is to construct a Markov chain with a stationary distribution equal to the target sampling distribution, using the states of the chain to generate random numbers after an initial burn-in period in which the state distribution converges to the target.

Using the Metropolis-Hastings Algorithm

The Metropolis-Hastings algorithm draws samples from a distribution that is only known up to a constant. Random numbers are generated from a distribution with a probability density function that is equal to or proportional to a proposal function.

To generate random numbers:

- 1 Assume an initial value $x(t)$.
- 2 Draw a sample, $y(t)$, from a proposal distribution $q(y | x(t))$.
- 3 Accept $y(t)$ as the next sample $x(t + 1)$ with probability $r(x(t), y(t))$, and keep $x(t)$ as the next sample $x(t + 1)$ with probability $1 - r(x(t), y(t))$, where:

$$r(x, y) = \min \left\{ \frac{f(y) q(x | y)}{f(x) q(y | x)}, 1 \right\}$$

- 4 Increment $t \rightarrow t+1$, and repeat steps 2 and 3 until you get the desired number of samples.

Generate random numbers using the Metropolis-Hastings method with the `mhsample` function. To produce quality samples efficiently with the Metropolis-Hastings algorithm, it is crucial to select a good proposal distribution. If it is difficult to find an efficient proposal distribution, use the slice sampling algorithm (`slicesample`) without explicitly specifying a proposal distribution.

Using Slice Sampling

In instances where it is difficult to find an efficient Metropolis-Hastings proposal distribution, the slice sampling algorithm does not require an explicit specification. The slice sampling algorithm draws samples from the region under the density function using a sequence of vertical and horizontal steps. First, it selects a height at random from 0 to the density function $f(x)$. Then, it selects a new x value at random by sampling from the horizontal “slice” of the density above the selected height. A similar slice sampling algorithm is used for a multivariate distribution.

If a function $f(x)$ proportional to the density function is given, then do the following to generate random numbers:

- 1** Assume an initial value $x(t)$ within the domain of $f(x)$.
- 2** Draw a real value y uniformly from $(0, f(x(t)))$, thereby defining a horizontal “slice” as $S = \{x: y < f(x)\}$.
- 3** Find an interval $I = (L, R)$ around $x(t)$ that contains all, or much of the “slice” S .
- 4** Draw the new point $x(t+1)$ within this interval.
- 5** Increment $t \rightarrow t+1$ and repeat steps 2 through 4 until you get the desired number of samples.

Slice sampling can generate random numbers from a distribution with an arbitrary form of the density function, provided that an efficient numerical procedure is available to find the interval $I = (L, R)$, which is the “slice” of the density.

Generate random numbers using the slice sampling method with the `slicesample` function.

Generating Quasi-Random Numbers

In this section...
“Quasi-Random Sequences” on page 6-15
“Quasi-Random Point Sets” on page 6-16
“Quasi-Random Streams” on page 6-23

Quasi-Random Sequences

Quasi-random number generators (QRNGs) produce highly uniform samples of the unit hypercube. QRNGs minimize the *discrepancy* between the distribution of generated points and a distribution with equal proportions of points in each sub-cube of a uniform partition of the hypercube. As a result, QRNGs systematically fill the “holes” in any initial segment of the generated quasi-random sequence.

Unlike the pseudorandom sequences described in “Common Generation Methods” on page 6-5, quasi-random sequences fail many statistical tests for randomness. Approximating true randomness, however, is not their goal. Quasi-random sequences seek to fill space uniformly, and to do so in such a way that initial segments approximate this behavior up to a specified density.

QRNG applications include:

- **Quasi-Monte Carlo (QMC) integration.** Monte Carlo techniques are often used to evaluate difficult, multi-dimensional integrals without a closed-form solution. QMC uses quasi-random sequences to improve the convergence properties of these techniques.
- **Space-filling experimental designs.** In many experimental settings, taking measurements at every factor setting is expensive or infeasible. Quasi-random sequences provide efficient, uniform sampling of the design space.
- **Global optimization.** Optimization algorithms typically find a local optimum in the neighborhood of an initial value. By using a quasi-random sequence of initial values, searches for global optima uniformly sample the basins of attraction of all local minima.

Example: Using Scramble, Leap, and Skip

Imagine a simple 1-D sequence that produces the integers from 1 to 10. This is the basic sequence and the first three points are [1,2,3]:

1 2 3 4 5 6 7 8 9 10

Now look at how Scramble, Leap, and Skip work together:

- **Scramble** — Scrambling shuffles the points in one of several different ways. In this example, assume a scramble turns the sequence into 1,3,5,7,9,2,4,6,8,10. The first three points are now [1,3,5]:

1 3 5 7 9 2 4 6 8 10

- **Skip** — A Skip value specifies the number of initial points to ignore. In this example, set the Skip value to 2. The sequence is now 5,7,9,2,4,6,8,10 and the first three points are [5,7,9]:

1 3 5 7 9 2 4 6 8 10

- **Leap** — A Leap value specifies the number of points to ignore for each one you take. Continuing the example with the Skip set to 2, if you set the Leap to 1, the sequence uses every other point. In this example, the sequence is now 5,9,4,8 and the first three points are [5,9,4]:

1 3 5 7 9 2 4 6 8 10

Quasi-Random Point Sets

Statistics Toolbox functions support these quasi-random sequences:

- **Halton sequences.** Produced by the `haltonset` function. These sequences use different prime bases to form successively finer uniform partitions of the unit interval in each dimension.

- **Sobol sequences.** Produced by the `sobolset` function. These sequences use a base of 2 to form successively finer uniform partitions of the unit interval, and then reorder the coordinates in each dimension.
- **Latin hypercube sequences.** Produced by the `lhsdesign` function. Though not quasi-random in the sense of minimizing discrepancy, these sequences nevertheless produce sparse uniform samples useful in experimental designs.

Quasi-random sequences are functions from the positive integers to the unit hypercube. To be useful in application, an initial *point set* of a sequence must be generated. Point sets are matrices of size n -by- d , where n is the number of points and d is the dimension of the hypercube being sampled. The functions `haltonset` and `sobolset` construct point sets with properties of a specified quasi-random sequence. Initial segments of the point sets are generated by the `net` method of the `grandset` class (parent class of the `haltonset` class and `sobolset` class), but points can be generated and accessed more generally using parenthesis indexing.

Because of the way in which quasi-random sequences are generated, they may contain undesirable correlations, especially in their initial segments, and especially in higher dimensions. To address this issue, quasi-random point sets often *skip*, *leap* over, or *scramble* values in a sequence. The `haltonset` and `sobolset` functions allow you to specify both a `Skip` and a `Leap` property of a quasi-random sequence, and the `scramble` method of the `grandset` class allows you apply a variety of scrambling techniques. Scrambling reduces correlations while also improving uniformity.

Example: Generate a Quasi-Random Point Set

This example uses `haltonset` to construct a 2-D Halton point set—an object, `p`, of the `haltonset` class—that skips the first 1000 values of the sequence and then retains every 101st point:

```
p = haltonset(2, 'Skip', 1e3, 'Leap', 1e2)
p =
  Halton point set in 2 dimensions (8.918019e+013 points)
  Properties:
    Skip : 1000
    Leap : 100
    ScrambleMethod : none
```

The object `p` encapsulates properties of the specified quasi-random sequence. The point set is finite, with a length determined by the `Skip` and `Leap` properties and by limits on the size of point set indices (maximum value of 2^{53}).

Use `scramble` to apply reverse-radix scrambling:

```
p = scramble(p, 'RR2')
p =
  Halton point set in 2 dimensions (8.918019e+013 points)
  Properties:
    Skip : 1000
    Leap : 100
    ScrambleMethod : RR2
```

Use `net` to generate the first 500 points:

```
X0 = net(p,500);
```

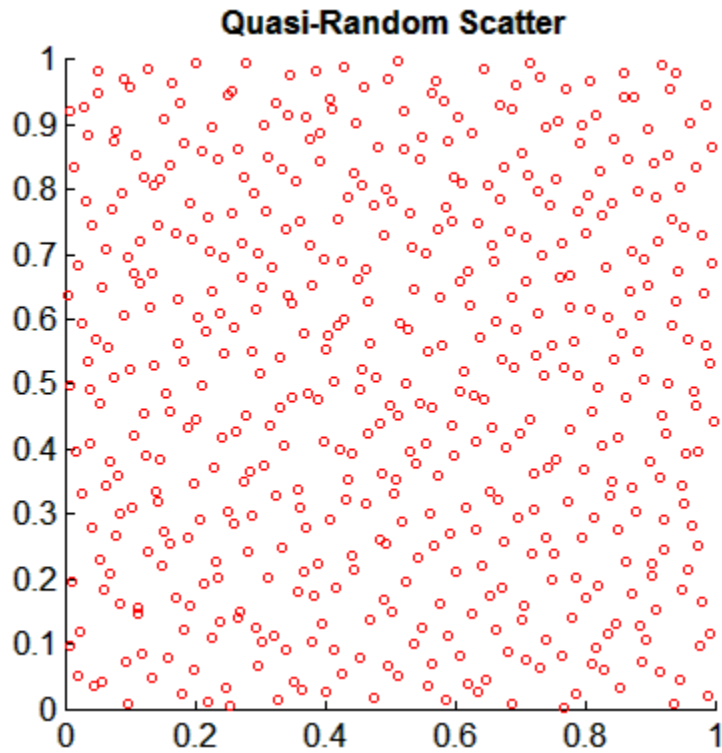
This is equivalent to:

```
X0 = p(1:500,:);
```

Values of the point set `X0` are not generated and stored in memory until you access `p` using `net` or parenthesis indexing.

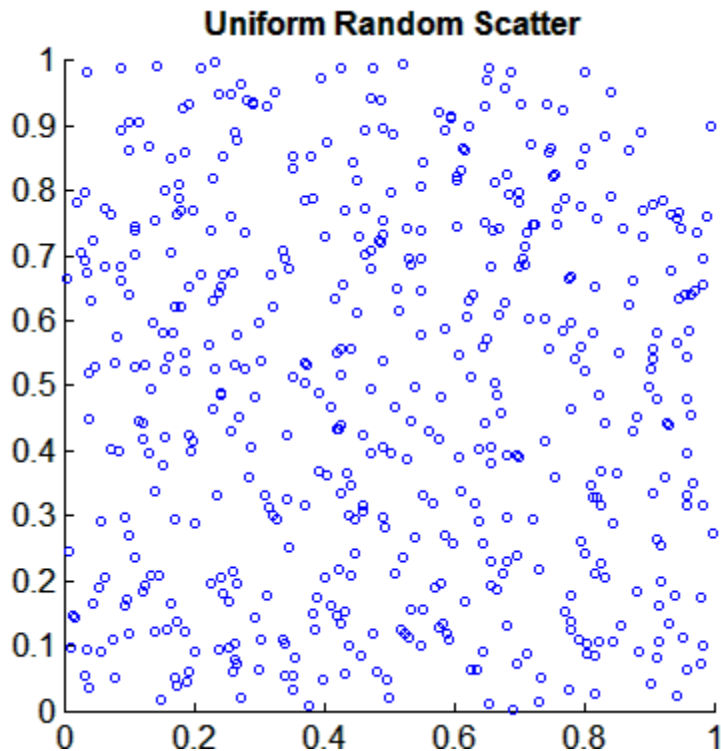
To appreciate the nature of quasi-random numbers, create a scatter of the two dimensions in `X0`:

```
scatter(X0(:,1),X0(:,2),5, 'r')
axis square
title('\bf Quasi-Random Scatter')
```



Compare this to a scatter of uniform pseudorandom numbers generated by the MATLAB `rand` function:

```
X = rand(500,2);  
  
scatter(X(:,1),X(:,2),5,'b')  
axis square  
title('\bf Uniform Random Scatter')
```



The quasi-random scatter appears more uniform, avoiding the clumping in the pseudorandom scatter.

In a statistical sense, quasi-random numbers are too uniform to pass traditional tests of randomness. For example, a Kolmogorov-Smirnov test, performed by `kstest`, is used to assess whether or not a point set has a uniform random distribution. When performed repeatedly on uniform pseudorandom samples, such as those generated by `rand`, the test produces a uniform distribution of p -values:

```
nTests = 1e5;
sampSize = 50;
PVALS = zeros(nTests,1);
for test = 1:nTests
    x = rand(sampSize,1);
    [h,pval] = kstest(x,[x,x]);
```

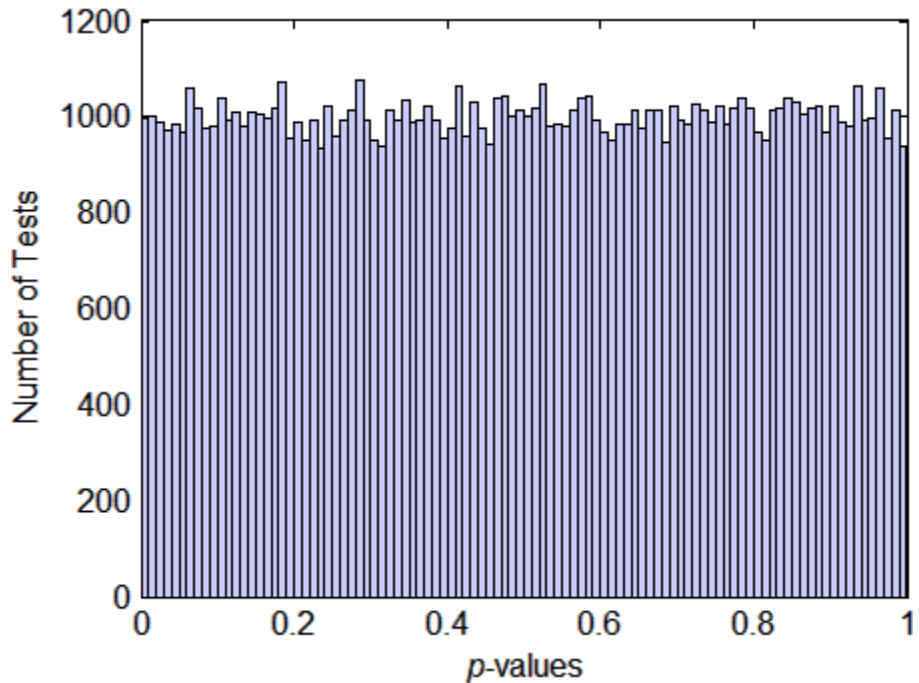


```

        PVALS(test) = pval;
    end

    hist(PVALS,100)
    set(get(gca,'Children'),'FaceColor',[.8 .8 1])
    xlabel('\it p}-values')
    ylabel('Number of Tests')

```



The results are quite different when the test is performed repeatedly on uniform quasi-random samples:

```

p = haltonset(1,'Skip',1e3,'Leap',1e2);
p = scramble(p,'RR2');

nTests = 1e5;
sampSize = 50;
PVALS = zeros(nTests,1);
for test = 1:nTests

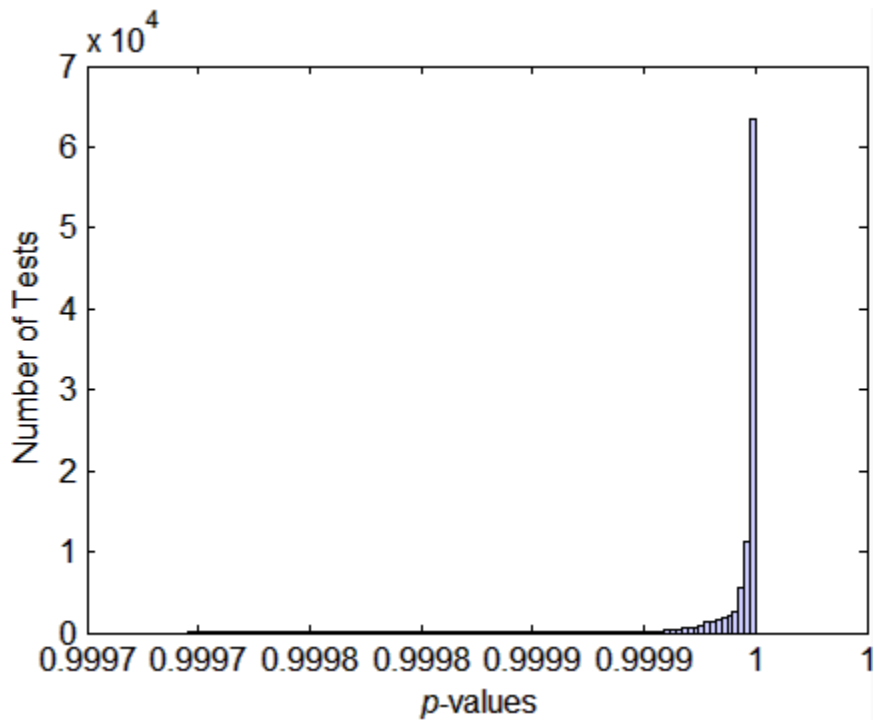
```

```

        x = p(test:test+(sampSize-1),:);
        [h,pval] = kstest(x,[x,x]);
        PVALS(test) = pval;
    end

    hist(PVALS,100)
    set(get(gca,'Children'),'FaceColor',[.8 .8 1])
    xlabel('\it p}-values')
    ylabel('Number of Tests')

```



Small p -values call into question the null hypothesis that the data are uniformly distributed. If the hypothesis is true, about 5% of the p -values are expected to fall below 0.05. The results are remarkably consistent in their failure to challenge the hypothesis.

Quasi-Random Streams

Quasi-random *streams*, produced by the `grandstream` function, are used to generate sequential quasi-random outputs, rather than point sets of a specific size. Streams are used like pseudoRNGS, such as `rand`, when client applications require a source of quasi-random numbers of indefinite size that can be accessed intermittently. Properties of a quasi-random stream, such as its type (Halton or Sobol), dimension, skip, leap, and scramble, are set when the stream is constructed.

In implementation, quasi-random streams are essentially very large quasi-random point sets, though they are accessed differently. The *state* of a quasi-random stream is the scalar index of the next point to be taken from the stream. Use the `grand` method of the `grandstream` class to generate points from the stream, starting from the current state. Use the `reset` method to reset the state to 1. Unlike point sets, streams do not support parenthesis indexing.

Example: Generate a Quasi-Random Stream

For example, the following code, taken from the example at the end of “Quasi-Random Point Sets” on page 6-16, uses `haltonset` to create a quasi-random point set `p`, and then repeatedly increments the index into the point set, `test`, to generate different samples:

```
p = haltonset(1,'Skip',1e3,'Leap',1e2);
p = scramble(p,'RR2');

nTests = 1e5;
sampSize = 50;
PVALS = zeros(nTests,1);
for test = 1:nTests
    x = p(test:test+(sampSize-1),:);
    [h,pval] = kstest(x,[x,x]);
    PVALS(test) = pval;
end
```

The same results are obtained by using `grandstream` to construct a quasi-random stream `q` based on the point set `p` and letting the stream take care of increments to the index:

```
p = haltonset(1,'Skip',1e3,'Leap',1e2);
p = scramble(p,'RR2');
q = grandstream(p)

nTests = 1e5;
sampSize = 50;
PVALS = zeros(nTests,1);
for test = 1:nTests
    X = grand(q,sampSize);
    [h,pval] = kstest(X,[X,X]);
    PVALS(test) = pval;
end
```

Generating Data Using Flexible Families of Distributions

In this section...

“Pearson and Johnson Systems” on page 6-25

“Generating Data Using the Pearson System” on page 6-26

“Generating Data Using the Johnson System” on page 6-28

Pearson and Johnson Systems

As described in “Using Probability Distributions” on page 5-2, choosing an appropriate parametric family of distributions to model your data can be based on *a priori* or *a posteriori* knowledge of the data-producing process, but the choice is often difficult. The *Pearson and Johnson systems* can make such a choice unnecessary. Each system is a flexible parametric family of distributions that includes a wide range of distribution shapes, and it is often possible to find a distribution within one of these two systems that provides a good match to your data.

Data Input

The following parameters define each member of the Pearson and Johnson systems

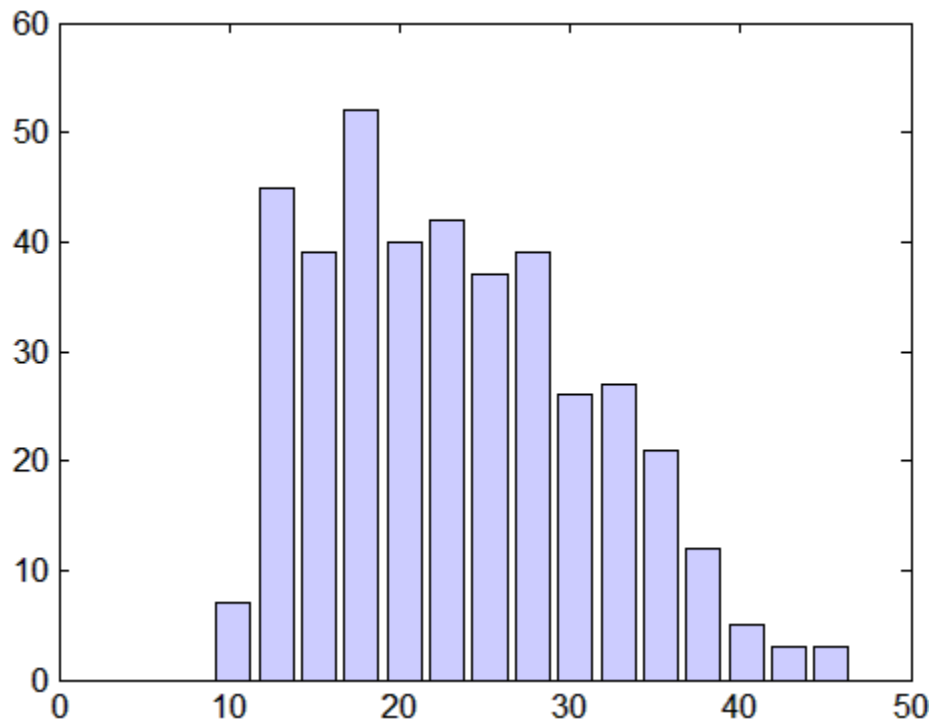
- Mean — Estimated by mean
- Standard deviation — Estimated by std
- Skewness — Estimated by skewness
- Kurtosis — Estimated by kurtosis

These statistics can also be computed with the moment function. The Johnson system, while based on these four parameters, is more naturally described using quantiles, estimated by the quantile function.

The Statistics Toolbox functions `pearsrnd` and `johnsrnd` take input arguments defining a distribution (parameters or quantiles, respectively) and return the type and the coefficients of the distribution in the corresponding system. Both functions also generate random numbers from the specified distribution.

As an example, load the data in `carbig.mat`, which includes a variable `MPG` containing measurements of the gas mileage for each car.

```
load carbig
MPG = MPG(~isnan(MPG));
[n,x] = hist(MPG,15);
bar(x,n)
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
```



The following two sections model the distribution with members of the Pearson and Johnson systems, respectively.

Generating Data Using the Pearson System

The statistician Karl Pearson devised a system, or family, of distributions that includes a unique distribution corresponding to every valid combination of mean, standard deviation, skewness, and kurtosis. If you compute sample

values for each of these moments from data, it is easy to find the distribution in the Pearson system that matches these four moments and to generate a random sample.

The Pearson system embeds seven basic types of distribution together in a single parametric framework. It includes common distributions such as the normal and t distributions, simple transformations of standard distributions such as a shifted and scaled beta distribution and the inverse gamma distribution, and one distribution—the Type IV—that is not a simple transformation of any standard distribution.

For a given set of moments, there are distributions that are not in the system that also have those same first four moments, and the distribution in the Pearson system may not be a good match to your data, particularly if the data are multimodal. But the system does cover a wide range of distribution shapes, including both symmetric and skewed distributions.

To generate a sample from the Pearson distribution that closely matches the MPG data, simply compute the four sample moments and treat those as distribution parameters.

```
moments = {mean(MPG), std(MPG), skewness(MPG), kurtosis(MPG)};
[r, type] = pearsrnd(moments{:}, 10000, 1);
```

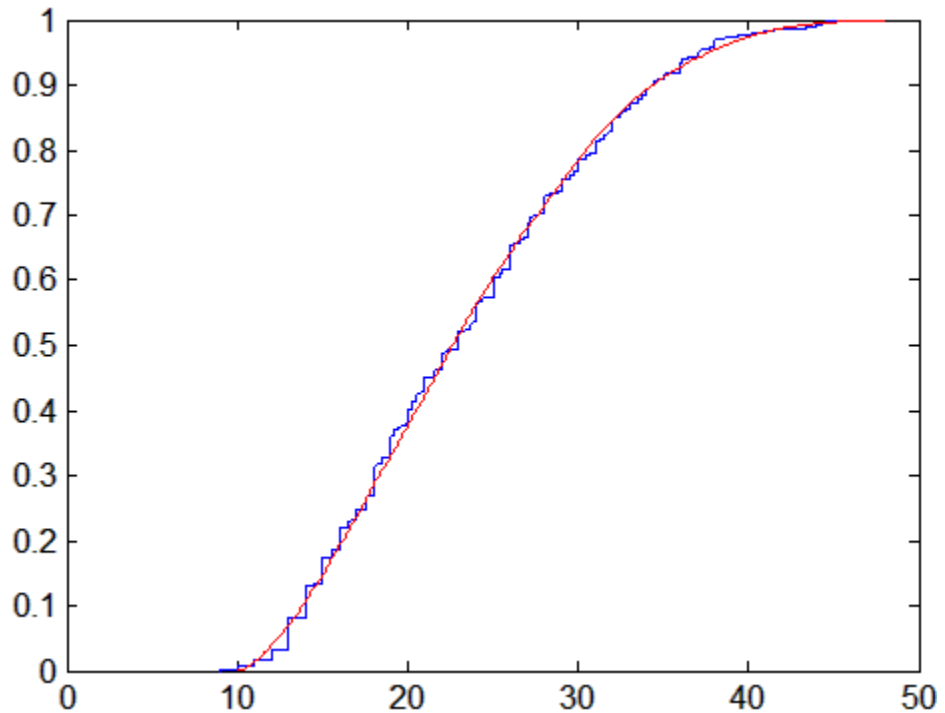
The optional second output from `pearsrnd` indicates which type of distribution within the Pearson system matches the combination of moments.

```
type
type =
    1
```

In this case, `pearsrnd` has determined that the data are best described with a Type I Pearson distribution, which is a shifted, scaled beta distribution.

Verify that the sample resembles the original data by overlaying the empirical cumulative distribution functions.

```
ecdf(MPG);
[Fi, xi] = ecdf(r);
hold on, stairs(xi, Fi, 'r'); hold off
```



Generating Data Using the Johnson System

Statistician Norman Johnson devised a different system of distributions that also includes a unique distribution for every valid combination of mean, standard deviation, skewness, and kurtosis. However, since it is more natural to describe distributions in the Johnson system using quantiles, working with this system is different than working with the Pearson system.

The Johnson system is based on three possible transformations of a normal random variable, plus the identity transformation. The three nontrivial cases are known as SL, SU, and SB, corresponding to exponential, logistic, and hyperbolic sine transformations. All three can be written as

$$X = \gamma + \delta \cdot \Gamma\left(\frac{(Z-\xi)}{\lambda}\right)$$

where Z is a standard normal random variable, Γ is the transformation, and γ , δ , ξ , and λ are scale and location parameters. The fourth case, SN, is the identity transformation.

To generate a sample from the Johnson distribution that matches the MPG data, first define the four quantiles to which the four evenly spaced standard normal quantiles of -1.5, -0.5, 0.5, and 1.5 should be transformed. That is, you compute the sample quantiles of the data for the cumulative probabilities of 0.067, 0.309, 0.691, and 0.933.

```
probs = normcdf([-1.5 -0.5 0.5 1.5])
probs =
    0.066807    0.30854    0.69146    0.93319

quantiles = quantile(MPG,probs)
quantiles =
    13.0000    18.0000    27.2000    36.0000
```

Then treat those quantiles as distribution parameters.

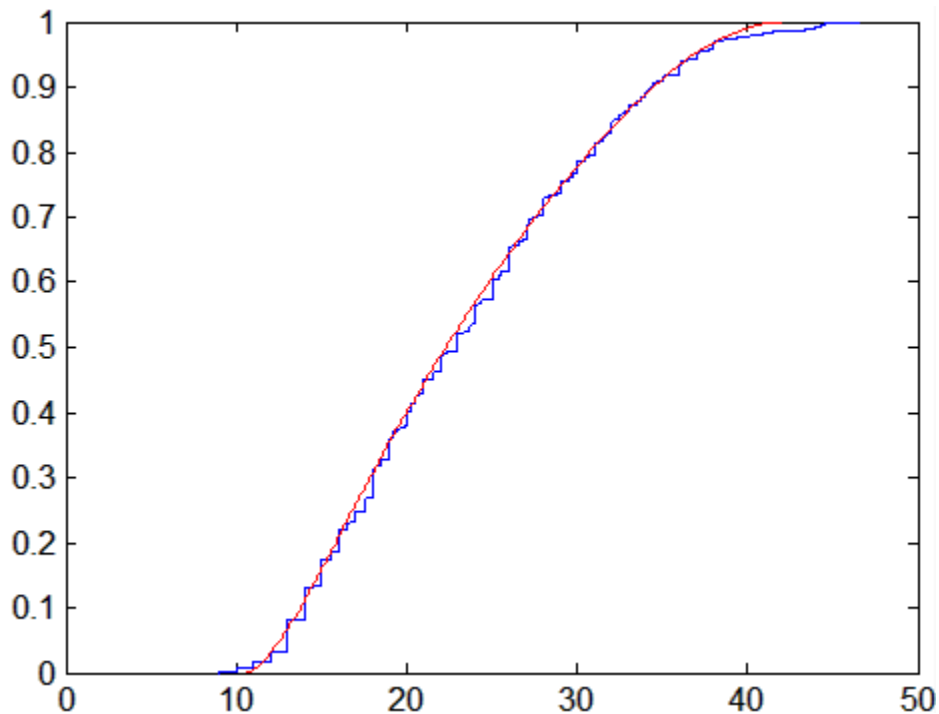
```
[r1,type] = johnsrnd(quantiles,10000,1);
```

The optional second output from `johnsrnd` indicates which type of distribution within the Johnson system matches the quantiles.

```
type
type =
SB
```

You can verify that the sample resembles the original data by overlaying the empirical cumulative distribution functions.

```
ecdf(MPG);
[Fi,xi] = ecdf(r1);
hold on, stairs(xi,Fi,'r'); hold off
```

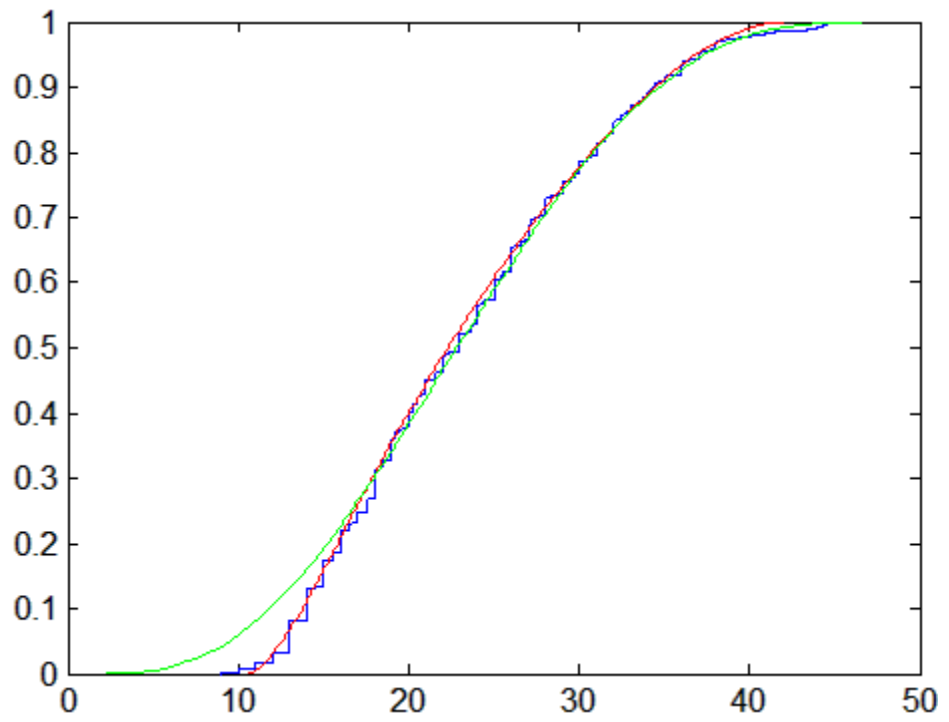


In some applications, it may be important to match the quantiles better in some regions of the data than in others. To do that, specify four evenly spaced standard normal quantiles at which you want to match the data, instead of the default -1.5 , -0.5 , 0.5 , and 1.5 . For example, you might care more about matching the data in the right tail than in the left, and so you specify standard normal quantiles that emphasizes the right tail.

```
qnorm = [-.5 .25 1 1.75];
probs = normcdf(qnorm);
qemp = quantile(MPG,probs);
r2 = johnsrnd([qnorm; qemp],10000,1);
```

However, while the new sample matches the original data better in the right tail, it matches much worse in the left tail.

```
[Fj,xj] = ecdf(r2);
hold on, stairs(xj,Fj,'g'); hold off
```



Hypothesis Tests

- “Introduction to Hypothesis Tests” on page 7-2
- “Hypothesis Test Terminology” on page 7-3
- “Hypothesis Test Assumptions” on page 7-5
- “Hypothesis Testing” on page 7-7
- “Available Hypothesis Tests” on page 7-13

Introduction to Hypothesis Tests

Hypothesis testing is a common method of drawing inferences about a population based on statistical evidence from a sample.

As an example, suppose someone says that at a certain time in the state of Massachusetts the average price of a gallon of regular unleaded gas was \$1.15. How could you determine the truth of the statement? You could try to find prices at every gas station in the state at the time. That approach would be definitive, but it could be time-consuming, costly, or even impossible.

A simpler approach would be to find prices at a small number of randomly selected gas stations around the state, and then compute the sample average.

Sample averages differ from one another due to chance variability in the selection process. Suppose your sample average comes out to be \$1.18. Is the \$0.03 difference an artifact of random sampling or significant evidence that the average price of a gallon of gas was in fact greater than \$1.15? Hypothesis testing is a statistical method for making such decisions.

Hypothesis Test Terminology

All hypothesis tests share the same basic terminology and structure.

- A *null hypothesis* is an assertion about a population that you would like to test. It is “null” in the sense that it often represents a status quo belief, such as the absence of a characteristic or the lack of an effect. It may be formalized by asserting that a population parameter, or a combination of population parameters, has a certain value. In the example given in the “Introduction to Hypothesis Tests” on page 7-2, the null hypothesis would be that the average price of gas across the state was \$1.15. This is written $H_0: \mu = 1.15$.
- An *alternative hypothesis* is a contrasting assertion about the population that can be tested against the null hypothesis. In the example given in the “Introduction to Hypothesis Tests” on page 7-2, possible alternative hypotheses are:
 - $H_1: \mu \neq 1.15$ — State average was different from \$1.15 (two-tailed test)
 - $H_1: \mu > 1.15$ — State average was greater than \$1.15 (right-tail test)
 - $H_1: \mu < 1.15$ — State average was less than \$1.15 (left-tail test)
- To conduct a hypothesis test, a random sample from the population is collected and a relevant *test statistic* is computed to summarize the sample. This statistic varies with the type of test, but its distribution under the null hypothesis must be known (or assumed).
- The *p value* of a test is the probability, under the null hypothesis, of obtaining a value of the test statistic as extreme or more extreme than the value computed from the sample.
- The *significance level* of a test is a threshold of probability α agreed to before the test is conducted. A typical value of α is 0.05. If the *p* value of a test is less than α , the test rejects the null hypothesis. If the *p* value is greater than α , there is insufficient evidence to reject the null hypothesis. Note that lack of evidence for rejecting the null hypothesis is not evidence for accepting the null hypothesis. Also note that substantive “significance” of an alternative cannot be inferred from the statistical significance of a test.
- The significance level α can be interpreted as the probability of rejecting the null hypothesis when it is actually true—a *type I error*. The distribution of the test statistic under the null hypothesis determines the probability

α of a type I error. Even if the null hypothesis is not rejected, it may still be false—a *type II error*. The distribution of the test statistic under the alternative hypothesis determines the probability β of a type II error. Type II errors are often due to small sample sizes. The *power* of a test, $1 - \beta$, is the probability of correctly rejecting a false null hypothesis.

- Results of hypothesis tests are often communicated with a *confidence interval*. A confidence interval is an estimated range of values with a specified probability of containing the true population value of a parameter. Upper and lower bounds for confidence intervals are computed from the sample estimate of the parameter and the known (or assumed) sampling distribution of the estimator. A typical assumption is that estimates will be normally distributed with repeated sampling (as dictated by the Central Limit Theorem). Wider confidence intervals correspond to poor estimates (smaller samples); narrow intervals correspond to better estimates (larger samples). If the null hypothesis asserts the value of a population parameter, the test rejects the null hypothesis when the hypothesized value lies outside the computed confidence interval for the parameter.

Hypothesis Test Assumptions

Different hypothesis tests make different assumptions about the distribution of the random variable being sampled in the data. These assumptions must be considered when choosing a test and when interpreting the results.

For example, the z -test (`ztest`) and the t -test (`ttest`) both assume that the data are independently sampled from a normal distribution. Statistics Toolbox functions are available for testing this assumption, such as `chi2gof`, `jbtest`, `lillietest`, and `normplot`.

Both the z -test and the t -test are relatively robust with respect to departures from this assumption, so long as the sample size n is large enough. Both tests compute a sample mean \bar{x} , which, by the Central Limit Theorem, has an approximately normal sampling distribution with mean equal to the population mean μ , regardless of the population distribution being sampled.

The difference between the z -test and the t -test is in the assumption of the standard deviation σ of the underlying normal distribution. A z -test assumes that σ is known; a t -test does not. As a result, a t -test must compute an estimate s of the standard deviation from the sample.

Test statistics for the z -test and the t -test are, respectively,

$$z = \frac{\bar{x} - \mu}{\sigma / \sqrt{n}}$$
$$t = \frac{\bar{x} - \mu}{s / \sqrt{n}}$$

Under the null hypothesis that the population is distributed with mean μ , the z -statistic has a standard normal distribution, $N(0,1)$. Under the same null hypothesis, the t -statistic has Student's t distribution with $n - 1$ degrees of freedom. For small sample sizes, Student's t distribution is flatter and wider than $N(0,1)$, compensating for the decreased confidence in the estimate s . As sample size increases, however, Student's t distribution approaches the standard normal distribution, and the two tests become essentially equivalent.

Knowing the distribution of the test statistic under the null hypothesis allows for accurate calculation of p -values. Interpreting p -values in the context of the test assumptions allows for critical analysis of test results.

Assumptions underlying Statistics Toolbox hypothesis tests are given in the reference pages for implementing functions.

Hypothesis Testing

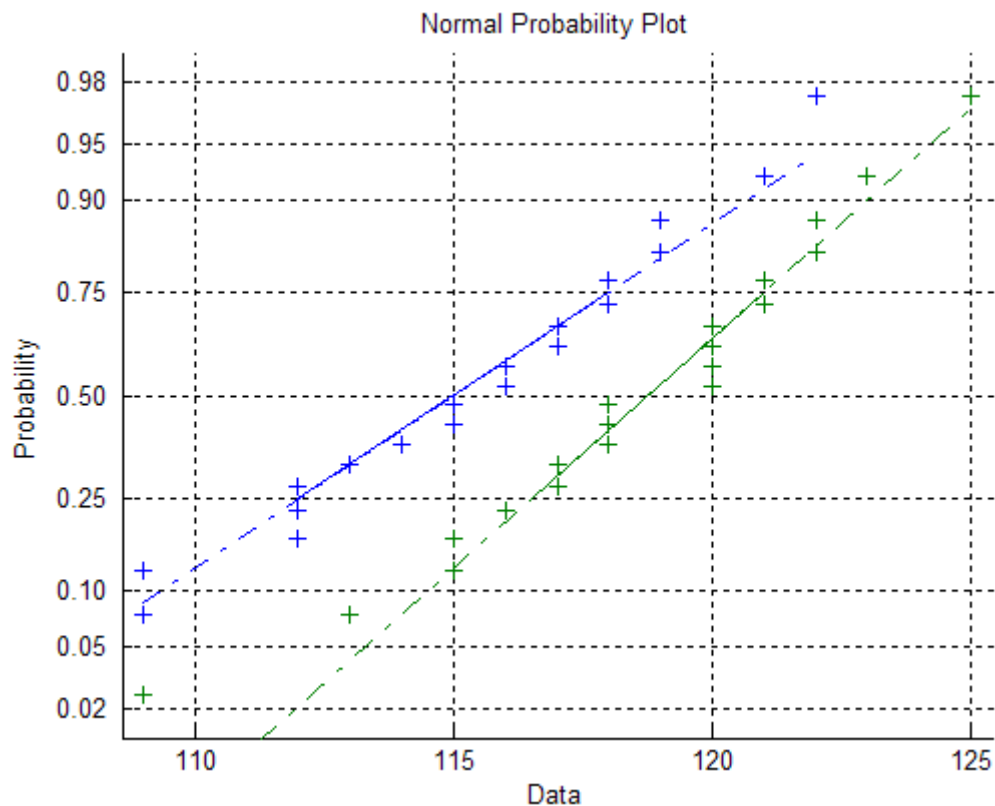
This example uses the gas price data in the file `gas.mat`. The file contains two random samples of prices for a gallon of gas around the state of Massachusetts in 1993. The first sample, `price1`, contains 20 random observations around the state on a single day in January. The second sample, `price2`, contains 20 random observations around the state one month later.

```
load gas
prices = [price1 price2];
```

As a first step, you might want to test the assumption that the samples come from normal distributions.

A normal probability plot gives a quick idea.

```
normplot(prices)
```



Both scatters approximately follow straight lines through the first and third quartiles of the samples, indicating approximate normal distributions. The February sample (the right-hand line) shows a slight departure from normality in the lower tail. A shift in the mean from January to February is evident.

A hypothesis test is used to quantify the test of normality. Since each sample is relatively small, a Lilliefors test is recommended.

```
lillietest(price1)
ans =
     0
lillietest(price2)
ans =
     0
```

The default significance level of `lillietest` is 5%. The logical 0 returned by each test indicates a failure to reject the null hypothesis that the samples are normally distributed. This failure may reflect normality in the population or it may reflect a lack of strong evidence against the null hypothesis due to the small sample size.

Now compute the sample means:

```
sample_means = mean(prices)
sample_means =
    115.1500    118.5000
```

You might want to test the null hypothesis that the mean price across the state on the day of the January sample was \$1.15. If you know that the standard deviation in prices across the state has historically, and consistently, been \$0.04, then a z -test is appropriate.

```
[h,pvalue,ci] = ztest(price1/100,1.15,0.04)
h =
     0
pvalue =
    0.8668
ci =
    1.1340
    1.1690
```

The logical output $h = 0$ indicates a failure to reject the null hypothesis at the default significance level of 5%. This is a consequence of the high probability under the null hypothesis, indicated by the p value, of observing a value as extreme or more extreme of the z -statistic computed from the sample. The 95% confidence interval on the mean [1.1340 1.1690] includes the hypothesized population mean of \$1.15.

Does the later sample offer stronger evidence for rejecting a null hypothesis of a state-wide average price of \$1.15 in February? The shift shown in the probability plot and the difference in the computed sample means suggest this. The shift might indicate a significant fluctuation in the market, raising questions about the validity of using the historical standard deviation. If a known standard deviation cannot be assumed, a *t*-test is more appropriate.

```
[h,pvalue,ci] = ttest(price2/100,1.15)
h =
     1
pvalue =
 4.9517e-004
ci =
 1.1675
 1.2025
```

The logical output $h = 1$ indicates a rejection of the null hypothesis at the default significance level of 5%. In this case, the 95% confidence interval on the mean does not include the hypothesized population mean of \$1.15.

You might want to investigate the shift in prices a little more closely. The function `ttest2` tests if two independent samples come from normal distributions with equal but unknown standard deviations and the same mean, against the alternative that the means are unequal.

```
[h,sig,ci] = ttest2(price1,price2)
h =
     1
sig =
 0.0083
ci =
-5.7845
-0.9155
```

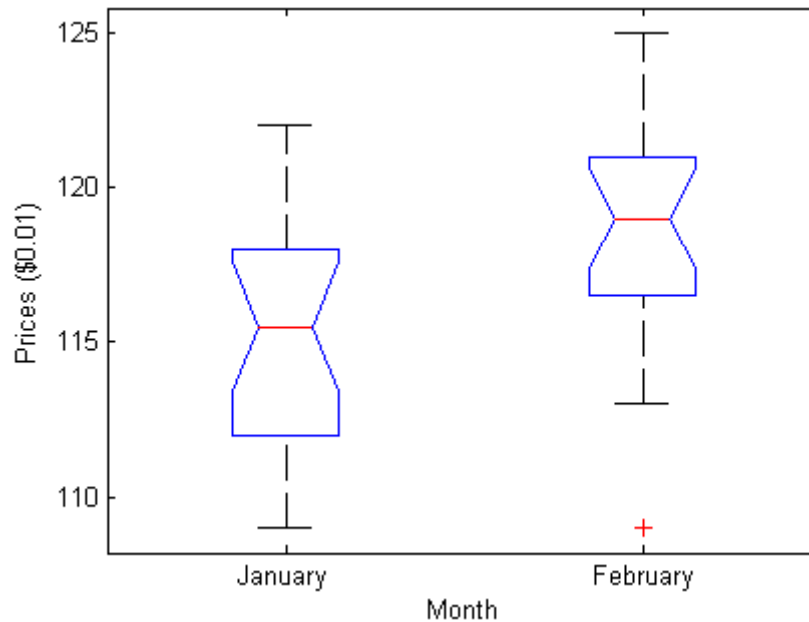
The null hypothesis is rejected at the default 5% significance level, and the confidence interval on the difference of means does not include the hypothesized value of 0.

A notched box plot is another way to visualize the shift.

```

boxplot(prices,1)
set(gca,'XTick',[1 2])
set(gca,'XtickLabel',{'January','February'})
xlabel('Month')
ylabel('Prices ($0.01)')

```



The plot displays the distribution of the samples around their medians. The heights of the notches in each box are computed so that the side-by-side boxes have nonoverlapping notches when their medians are different at a default 5% significance level. The computation is based on an assumption of normality in the data, but the comparison is reasonably robust for other distributions. The side-by-side plots provide a kind of visual hypothesis test, comparing medians rather than means. The plot above appears to barely reject the null hypothesis of equal medians.

The nonparametric Wilcoxon rank sum test, implemented by the function `ranksum`, can be used to quantify the test of equal medians. It tests if two independent samples come from identical continuous (not necessarily normal) distributions with equal medians, against the alternative that they do not have equal medians.

```
[p,h] = ranksum(price1,price2)
p =
    0.0095
h =
     1
```

The test rejects the null hypothesis of equal medians at the default 5% significance level.

Available Hypothesis Tests

Function	Description
ansaribradley	Ansari-Bradley test. Tests if two independent samples come from the same distribution, against the alternative that they come from distributions that have the same median and shape but different variances.
barttest	Bartlett's test. Tests if the variances of the data values along each principal component are equal, against the alternative that the variances are not all equal.
chi2gof	Chi-square goodness-of-fit test. Tests if a sample comes from a specified distribution, against the alternative that it does not come from that distribution.
dwtest	Durbin-Watson test. Tests if the residuals from a linear regression are uncorrelated, against the alternative that there is autocorrelation among them.
friedman	Friedman's test. Tests if the column effects in a two-way layout are all the same, against the alternative that the column effects are not all the same.
jbttest	Jarque-Bera test. Tests if a sample comes from a normal distribution with unknown mean and variance, against the alternative that it does not come from a normal distribution.
kruskalwallis	Kruskal-Wallis test. Tests if multiple samples are all drawn from the same populations (or equivalently, from different populations with the same distribution), against the alternative that they are not all drawn from the same population.
kstest	One-sample Kolmogorov-Smirnov test. Tests if a sample comes from a continuous distribution with specified parameters, against the alternative that it does not come from that distribution.

Function	Description
kstest2	Two-sample Kolmogorov-Smirnov test. Tests if two samples come from the same continuous distribution, against the alternative that they do not come from the same distribution.
lillietest	Lilliefors test. Tests if a sample comes from a distribution in the normal family, against the alternative that it does not come from a normal distribution.
linhypstest	Linear hypothesis test. Tests if $H*b = c$ for parameter estimates b with estimated covariance H and specified c , against the alternative that $H*b \neq c$.
ranksum	Wilcoxon rank sum test. Tests if two independent samples come from identical continuous distributions with equal medians, against the alternative that they do not have equal medians.
runstest	Runs test. Tests if a sequence of values comes in random order, against the alternative that the ordering is not random.
signrank	One-sample or paired-sample Wilcoxon signed rank test. Tests if a sample comes from a continuous distribution symmetric about a specified median, against the alternative that it does not have that median.
signtest	One-sample or paired-sample sign test. Tests if a sample comes from an arbitrary continuous distribution with a specified median, against the alternative that it does not have that median.
ttest	One-sample or paired-sample t -test. Tests if a sample comes from a normal distribution with unknown variance and a specified mean, against the alternative that it does not have that mean.

Function	Description
<code>ttest2</code>	Two-sample t -test. Tests if two independent samples come from normal distributions with unknown but equal (or, optionally, unequal) variances and the same mean, against the alternative that the means are unequal.
<code>vartest</code>	One-sample chi-square variance test. Tests if a sample comes from a normal distribution with specified variance, against the alternative that it comes from a normal distribution with a different variance.
<code>vartest2</code>	Two-sample F -test for equal variances. Tests if two independent samples come from normal distributions with the same variance, against the alternative that they come from normal distributions with different variances.
<code>vartestn</code>	Bartlett multiple-sample test for equal variances. Tests if multiple samples come from normal distributions with the same variance, against the alternative that they come from normal distributions with different variances.
<code>ztest</code>	One-sample z -test. Tests if a sample comes from a normal distribution with known variance and specified mean, against the alternative that it does not have that mean.

Note In addition to the previous functions, Statistics Toolbox functions are available for analysis of variance (ANOVA), which perform hypothesis tests in the context of linear modeling.

Analysis of Variance

- “Introduction to Analysis of Variance” on page 8-2
- “ANOVA” on page 8-3
- “MANOVA” on page 8-39

Introduction to Analysis of Variance

Analysis of variance (ANOVA) is a procedure for assigning sample variance to different sources and deciding whether the variation arises within or among different population groups. Samples are described in terms of variation around group means and variation of group means around an overall mean. If variations within groups are small relative to variations between groups, a difference in group means may be inferred. Hypothesis tests are used to quantify decisions.

ANOVA

In this section...

- “One-Way ANOVA” on page 8-3
- “Two-Way ANOVA” on page 8-9
- “N-Way ANOVA” on page 8-12
- “Other ANOVA Models” on page 8-26
- “Analysis of Covariance” on page 8-27
- “Nonparametric Methods” on page 8-35

One-Way ANOVA

- “Introduction to One-Way ANOVA” on page 8-3
- “Example: One-Way ANOVA” on page 8-4
- “Multiple Comparisons” on page 8-6
- “Example: Multiple Comparisons” on page 8-7

Introduction to One-Way ANOVA

The purpose of one-way ANOVA is to find out whether data from several groups have a common mean. That is, to determine whether the groups are actually different in the measured characteristic.

One-way ANOVA is a simple special case of the linear model. The one-way ANOVA form of the model is

$$y_{ij} = \alpha_{.j} + \varepsilon_{ij}$$

where:

- y_{ij} is a matrix of observations in which each column represents a different group.

- α_j is a matrix whose columns are the group means. (The “dot j ” notation means that α applies to all rows of column j . That is, the value α_{ij} is the same for all i .)
- ε_{ij} is a matrix of random disturbances.

The model assumes that the columns of y are a constant plus a random disturbance. You want to know if the constants are all the same.

Example: One-Way ANOVA

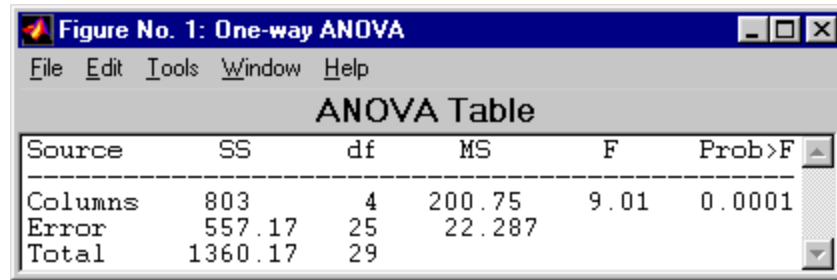
The data below comes from a study by Hogg and Ledolter [48] of bacteria counts in shipments of milk. The columns of the matrix `hogg` represent different shipments. The rows are bacteria counts from cartons of milk chosen randomly from each shipment. Do some shipments have higher counts than others?

```
load hogg
hogg
hogg =
```

24	14	11	7	19
15	7	9	7	24
21	12	7	4	19
27	17	13	7	15
33	14	12	12	10
23	16	18	18	20

```
[p,tbl,stats] = anova1(hogg);
p
p =
    1.1971e-04
```

The standard ANOVA table has columns for the sums of squares, degrees of freedom, mean squares (SS/df), F statistic, and p value.



The screenshot shows a window titled "Figure No. 1: One-way ANOVA" with a menu bar containing "File", "Edit", "Tools", "Window", and "Help". The main content is an ANOVA table with the following data:

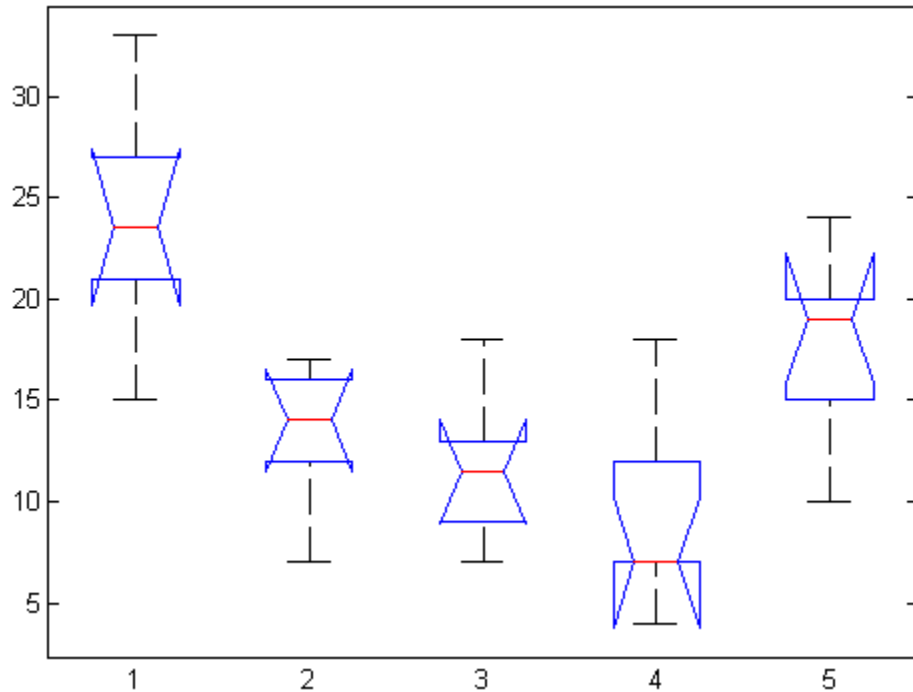
Source	SS	df	MS	F	Prob>F
Columns	803	4	200.75	9.01	0.0001
Error	557.17	25	22.287		
Total	1360.17	29			

You can use the F statistic to do a hypothesis test to find out if the bacteria counts are the same. `anova1` returns the p value from this hypothesis test.

In this case the p value is about 0.0001, a very small value. This is a strong indication that the bacteria counts from the different shipments are not the same. An F statistic as extreme as the observed F would occur by chance only once in 10,000 times if the counts were truly equal.

The p value returned by `anova1` depends on assumptions about the random disturbances ε_{ij} in the model equation. For the p value to be correct, these disturbances need to be independent, normally distributed, and have constant variance.

You can get some graphical assurance that the means are different by looking at the box plots in the second figure window displayed by `anova1`. Note, however, that the notches are used for a comparison of medians, not a comparison of means. For more information on this display, see “Box Plots” on page 4-6.



Multiple Comparisons

Sometimes you need to determine not just whether there are any differences among the means, but specifically which pairs of means are significantly different. It is tempting to perform a series of t tests, one for each pair of means, but this procedure has a pitfall.

In a t test, you compute a t statistic and compare it to a critical value. The critical value is chosen so that when the means are really the same (any apparent difference is due to random chance), the probability that the t statistic will exceed the critical value is small, say 5%. When the means are different, the probability that the statistic will exceed the critical value is larger.

In this example there are five means, so there are 10 pairs of means to compare. It stands to reason that if all the means are the same, and if there is a 5% chance of incorrectly concluding that there is a difference in one pair,

then the probability of making at least one incorrect conclusion among all 10 pairs is much larger than 5%.

Fortunately, there are procedures known as *multiple comparison procedures* that are designed to compensate for multiple tests.

Example: Multiple Comparisons

You can perform a multiple comparison test using the `multcompare` function and supplying it with the `stats` output from `anova1`.

```
load hogg
[p,tbl,stats] = anova1(hogg);
[c,m] = multcompare(stats)
c =
    1.0000    2.0000    2.4953    10.5000    18.5047
    1.0000    3.0000    4.1619    12.1667    20.1714
    1.0000    4.0000    6.6619    14.6667    22.6714
    1.0000    5.0000   -2.0047     6.0000    14.0047
    2.0000    3.0000   -6.3381     1.6667     9.6714
    2.0000    4.0000   -3.8381     4.1667    12.1714
    2.0000    5.0000  -12.5047    -4.5000     3.5047
    3.0000    4.0000   -5.5047     2.5000    10.5047
    3.0000    5.0000  -14.1714    -6.1667     1.8381
    4.0000    5.0000  -16.6714    -8.6667    -0.6619
m =
    23.8333    1.9273
    13.3333    1.9273
    11.6667    1.9273
     9.1667    1.9273
    17.8333    1.9273
```

The first output from `multcompare` has one row for each pair of groups, with an estimate of the difference in group means and a confidence interval for that group. For example, the second row has the values

```
1.0000    3.0000    4.1619    12.1667    20.1714
```

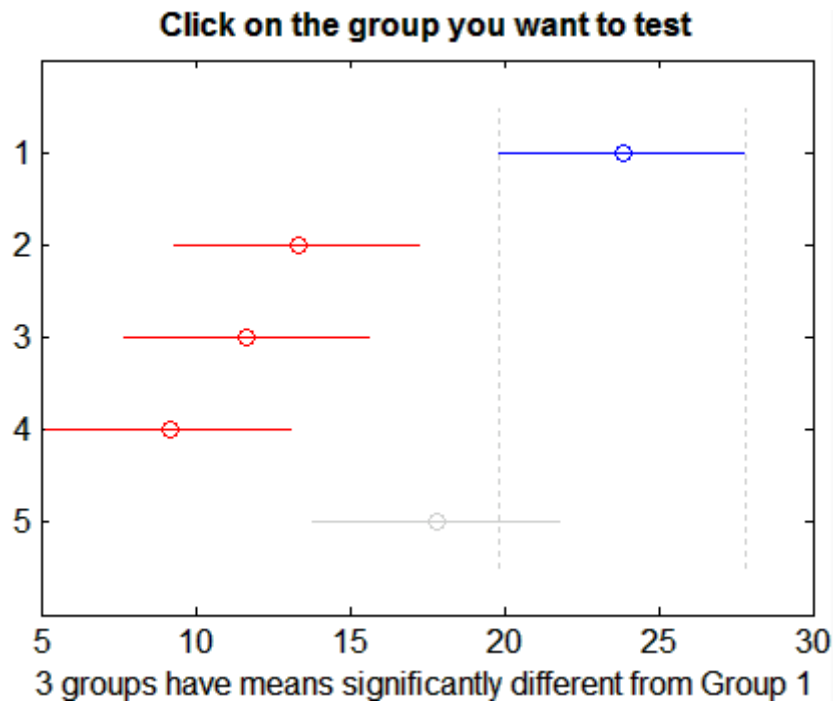
indicating that the mean of group 1 minus the mean of group 3 is estimated to be 12.1667, and a 95% confidence interval for this difference is

[4.1619, 20.1714]. This interval does not contain 0, so you can conclude that the means of groups 1 and 3 are different.

The second output contains the mean and its standard error for each group.

It is easier to visualize the difference between group means by looking at the graph that `multcompare` produces.

There are five groups. The graph instructs you to **Click on the group you want to test**. Three groups have slopes significantly different from group one.



The graph shows that group 1 is significantly different from groups 2, 3, and 4. By using the mouse to select group 4, you can determine that it is also significantly different from group 5. Other pairs are not significantly different.

Two-Way ANOVA

- “Introduction to Two-Way ANOVA” on page 8-9
- “Example: Two-Way ANOVA” on page 8-10

Introduction to Two-Way ANOVA

The purpose of two-way ANOVA is to find out whether data from several groups have a common mean. One-way ANOVA and two-way ANOVA differ in that the groups in two-way ANOVA have two categories of defining characteristics instead of one.

Suppose an automobile company has two factories, and each factory makes the same three models of car. It is reasonable to ask if the gas mileage in the cars varies from factory to factory as well as from model to model. There are two predictors, factory and model, to explain differences in mileage.

There could be an overall difference in mileage due to a difference in the production methods between factories. There is probably a difference in the mileage of the different models (irrespective of the factory) due to differences in design specifications. These effects are called *additive*.

Finally, a factory might make high mileage cars in one model (perhaps because of a superior production line), but not be different from the other factory for other models. This effect is called an *interaction*. It is impossible to detect an interaction unless there are duplicate observations for some combination of factory and car model.

Two-way ANOVA is a special case of the linear model. The two-way ANOVA form of the model is

$$y_{ijk} = \mu + \alpha_{.j} + \beta_i + \gamma_{ij} + \varepsilon_{ijk}$$

where, with respect to the automobile example above:

- y_{ijk} is a matrix of gas mileage observations (with row index i , column index j , and repetition index k).
- μ is a constant matrix of the overall mean gas mileage.

- α_j is a matrix whose columns are the deviations of each car's gas mileage (from the mean gas mileage μ) that are attributable to the car's *model*. All values in a given column of α_j are identical, and the values in each row of α_j sum to 0.
- β_i is a matrix whose rows are the deviations of each car's gas mileage (from the mean gas mileage μ) that are attributable to the car's *factory*. All values in a given row of β_i are identical, and the values in each column of β_i sum to 0.
- γ_{ij} is a matrix of interactions. The values in each row of γ_{ij} sum to 0, and the values in each column of γ_{ij} sum to 0.
- ε_{ijk} is a matrix of random disturbances.

Example: Two-Way ANOVA

The purpose of the example is to determine the effect of car model and factory on the mileage rating of cars.

```
load mileage
mileage
```

```
mileage =
```

```

33.3000  34.5000  37.4000
33.4000  34.8000  36.8000
32.9000  33.8000  37.6000
32.6000  33.4000  36.6000
32.5000  33.7000  37.0000
33.0000  33.9000  36.7000
```

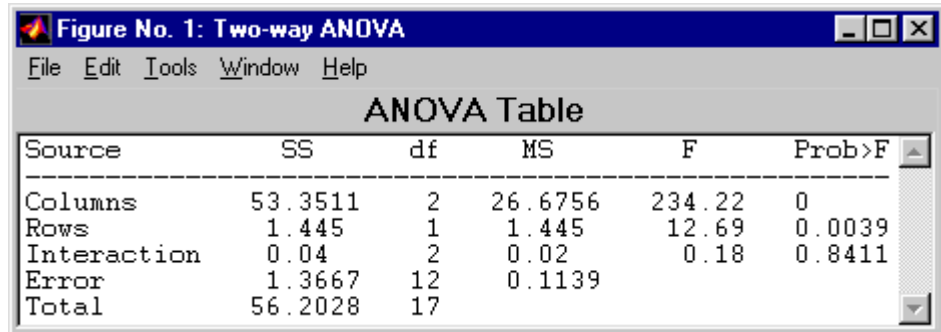
```
cars = 3;
[p,tbl,stats] = anova2(mileage,cars);
p
```

```
p =
0.0000    0.0039    0.8411
```

There are three models of cars (columns) and two factories (rows). The reason there are six rows in `mileage` instead of two is that each factory provides

three cars of each model for the study. The data from the first factory is in the first three rows, and the data from the second factory is in the last three rows.

The standard ANOVA table has columns for the sums of squares, degrees-of-freedom, mean squares (SS/df), F statistics, and p -values.



Source	SS	df	MS	F	Prob>F
Columns	53.3511	2	26.6756	234.22	0
Rows	1.445	1	1.445	12.69	0.0039
Interaction	0.04	2	0.02	0.18	0.8411
Error	1.3667	12	0.1139		
Total	56.2028	17			

You can use the F statistics to do hypotheses tests to find out if the mileage is the same across models, factories, and model-factory pairs (after adjusting for the additive effects). `anova2` returns the p value from these tests.

The p value for the model effect is zero to four decimal places. This is a strong indication that the mileage varies from one model to another. An F statistic as extreme as the observed F would occur by chance less than once in 10,000 times if the gas mileage were truly equal from model to model. If you used the `multcompare` function to perform a multiple comparison test, you would find that each pair of the three models is significantly different.

The p value for the factory effect is 0.0039, which is also highly significant. This indicates that one factory is out-performing the other in the gas mileage of the cars it produces. The observed p value indicates that an F statistic as extreme as the observed F would occur by chance about four out of 1000 times if the gas mileage were truly equal from factory to factory.

There does not appear to be any interaction between factories and models. The p value, 0.8411, means that the observed result is quite likely (84 out of 100 times) given that there is no interaction.

The p -values returned by `anova2` depend on assumptions about the random disturbances ε_{ijk} in the model equation. For the p -values to be correct these disturbances need to be independent, normally distributed, and have constant variance.

In addition, `anova2` requires that data be *balanced*, which in this case means there must be the same number of cars for each combination of model and factory. The next section discusses a function that supports unbalanced data with any number of predictors.

N-Way ANOVA

- “Introduction to N-Way ANOVA” on page 8-12
- “N-Way ANOVA with a Small Data Set” on page 8-13
- “N-Way ANOVA with a Large Data Set” on page 8-15
- “ANOVA with Random Effects” on page 8-19

Introduction to N-Way ANOVA

You can use N-way ANOVA to determine if the means in a set of data differ when grouped by multiple factors. If they do differ, you can determine which factors or combinations of factors are associated with the difference.

N-way ANOVA is a generalization of two-way ANOVA. For three factors, the model can be written

$$y_{ijkl} = \mu + \alpha_{.j.} + \beta_{i..} + \gamma_{..k} + (\alpha\beta)_{ij.} + (\alpha\gamma)_{i.k} + (\beta\gamma)_{.jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkl}$$

In this notation parameters with two subscripts, such as $(\alpha\beta)_{ij.}$, represent the interaction effect of two factors. The parameter $(\alpha\beta\gamma)_{ijk}$ represents the three-way interaction. An ANOVA model can have the full set of parameters or any subset, but conventionally it does not include complex interaction terms unless it also includes all simpler terms for those factors. For example, one would generally not include the three-way interaction without also including all two-way interactions.

The `anovan` function performs N-way ANOVA. Unlike the `anova1` and `anova2` functions, `anovan` does not expect data in a tabular form. Instead, it expects a vector of response measurements and a separate vector (or text array) containing the values corresponding to each factor. This input data format is more convenient than matrices when there are more than two factors or when the number of measurements per factor combination is not constant.

N-Way ANOVA with a Small Data Set

Consider the following two-way example using `anova2`.

```
m = [23 15 20;27 17 63;43 3 55;41 9 90]
m =
    23    15    20
    27    17    63
    43     3    55
    41     9    90
```

```
anova2(m,2)
```

```
ans =
    0.0197    0.2234    0.2663
```

The factor information is implied by the shape of the matrix `m` and the number of measurements at each factor combination (2). Although `anova2` does not actually require arrays of factor values, for illustrative purposes you could create them as follows.

```
cfactor = repmat(1:3,4,1)
```

```
cfactor =
     1     2     3
     1     2     3
     1     2     3
     1     2     3
```

```
rfactor = [ones(2,3); 2*ones(2,3)]
```

```
rfactor =
     1     1     1
```

```
1    1    1
2    2    2
2    2    2
```

The `cfactor` matrix shows that each column of `m` represents a different level of the column factor. The `rfactor` matrix shows that the top two rows of `m` represent one level of the row factor, and bottom two rows of `m` represent a second level of the row factor. In other words, each value `m(i, j)` represents an observation at column factor level `cfactor(i, j)` and row factor level `rfactor(i, j)`.

To solve the above problem with `anovan`, you need to reshape the matrices `m`, `cfactor`, and `rfactor` to be vectors.

```
m = m(:);
cfactor = cfactor(:);
rfactor = rfactor(:);
```

```
[m cfactor rfactor]
```

```
ans =
```

```
23    1    1
27    1    1
43    1    2
41    1    2
15    2    1
17    2    1
 3    2    2
 9    2    2
20    3    1
63    3    1
55    3    2
90    3    2
```

```
anovan(m, {cfactor rfactor}, 2)
```

```
ans =
```

```
0.0197
```

```
0.2234
0.2663
```

N-Way ANOVA with a Large Data Set

The previous example used `anova2` to study a small data set measuring car mileage. This example illustrates how to analyze a larger set of car data with mileage and other information on 406 cars made between 1970 and 1982. First, load the data set and look at the variable names.

```
load carbig
whos
```

Name	Size	Bytes	Class
Acceleration	406x1	3248	double array
Cylinders	406x1	3248	double array
Displacement	406x1	3248	double array
Horsepower	406x1	3248	double array
MPG	406x1	3248	double array
Model	406x36	29232	char array
Model_Year	406x1	3248	double array
Origin	406x7	5684	char array
Weight	406x1	3248	double array
cyl4	406x5	4060	char array
org	406x7	5684	char array
when	406x5	4060	char array

The example focusses on four variables. MPG is the number of miles per gallon for each of 406 cars (though some have missing values coded as NaN). The other three variables are factors: `cyl4` (four-cylinder car or not), `org` (car originated in Europe, Japan, or the USA), and `when` (car was built early in the period, in the middle of the period, or late in the period).

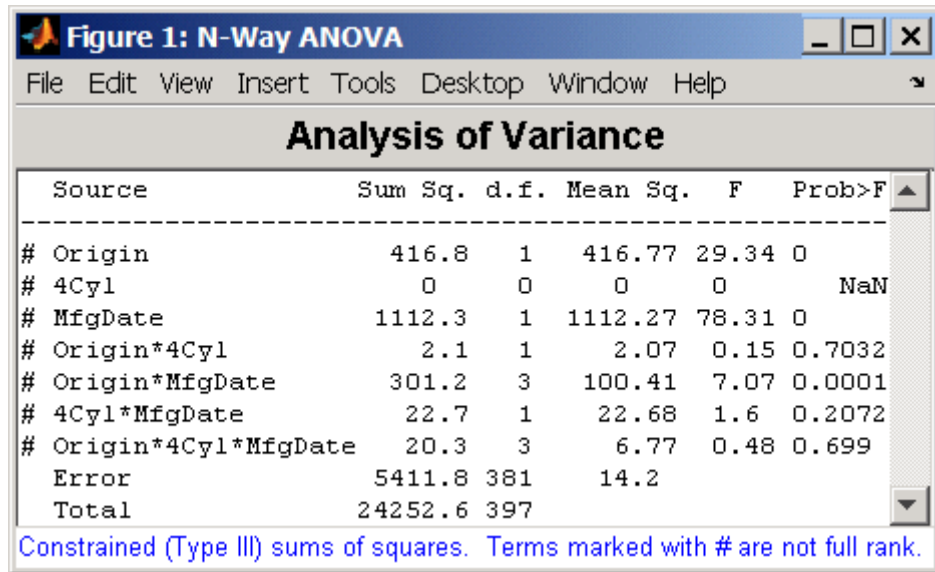
First, fit the full model, requesting up to three-way interactions and Type 3 sums-of-squares.

```
varnames = {'Origin';'4Cyl';'MfgDate'};
anovan(MPG,{org cyl4 when},3,3,varnames)
ans =
    0.0000
```

```

NaN
0
0.7032
0.0001
0.2072
0.6990

```



Note that many terms are marked by a # symbol as not having full rank, and one of them has zero degrees of freedom and is missing a p value. This can happen when there are missing factor combinations and the model has higher-order terms. In this case, the cross-tabulation below shows that there are no cars made in Europe during the early part of the period with other than four cylinders, as indicated by the 0 in `table(2,1,1)`.

```
[table, chi2, p, factorvals] = crosstab(org,when,cyl4)
```

```
table(:, :, 1) =
```

```

82    75    25
0      4     3
3      3     4

```

```

table(:, :, 2) =
    12    22    38
    23    26    17
    12    25    32

chi2 =

    207.7689

p =

    0

factorvals =

    'USA'      'Early'    'Other'
    'Europe'  'Mid'      'Four'
    'Japan'   'Late'     []

```

Consequently it is impossible to estimate the three-way interaction effects, and including the three-way interaction term in the model makes the fit singular.

Using even the limited information available in the ANOVA table, you can see that the three-way interaction has a p value of 0.699, so it is not significant. So this time you examine only two-way interactions.

```

[p,tbl,stats,terms] = anovan(MPG,{org cyl4 when},2,3,varnames);
terms

terms =

    1    0    0
    0    1    0
    0    0    1
    1    1    0
    1    0    1
    0    1    1

```

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Origin	532.6	2	266.29	18.82	0
4Cyl	1769.8	1	1769.85	125.11	0
MfgDate	2887.1	2	1443.55	102.05	0
Origin*4Cyl	12.5	2	6.27	0.44	0.6422
Origin*MfgDate	350.4	4	87.59	6.19	0.0001
4Cyl*MfgDate	31	2	15.52	1.1	0.3348
Error	5432.1	384	14.15		
Total	24252.6	397			

Constrained (Type III) sums of squares.

Now all terms are estimable. The p -values for interaction term 4 (Origin*4Cyl) and interaction term 6 (4Cyl*MfgDate) are much larger than a typical cutoff value of 0.05, indicating these terms are not significant. You could choose to omit these terms and pool their effects into the error term. The output terms variable returns a matrix of codes, each of which is a bit pattern representing a term. You can omit terms from the model by deleting their entries from terms and running anovan again, this time supplying the resulting vector as the model argument.

```
terms([4 6],:) = []
```

```
terms =
```

```

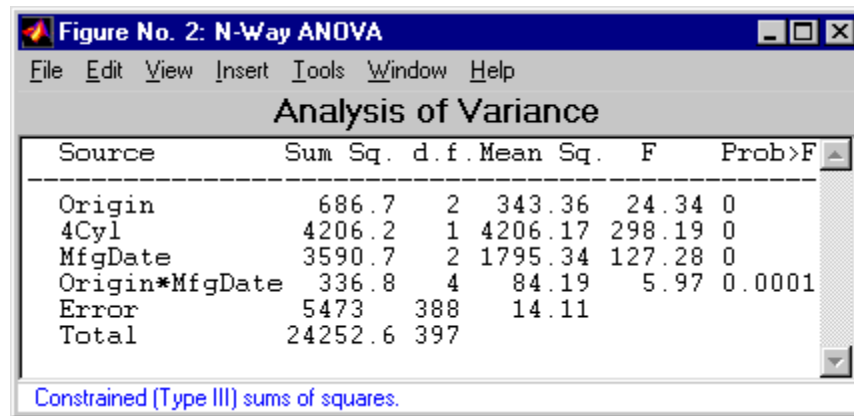
1    0    0
0    1    0
0    0    1
1    0    1
```

```
anovan(MPG,{org cyl4 when},terms,3,varnames)
```

```
ans =
```

```
1.0e-003 *
```

0.0000
0
0
0.1140



Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Origin	686.7	2	343.36	24.34	0
4Cyl	4206.2	1	4206.17	298.19	0
MfgDate	3590.7	2	1795.34	127.28	0
Origin*MfgDate	336.8	4	84.19	5.97	0.0001
Error	5473	388	14.11		
Total	24252.6	397			

Constrained (Type III) sums of squares.

Now you have a more parsimonious model indicating that the mileage of these cars seems to be related to all three factors, and that the effect of the manufacturing date depends on where the car was made.

ANOVA with Random Effects

- “Introduction to ANOVA with Random Effects” on page 8-19
- “Setting Up the Model” on page 8-20
- “Fitting a Random Effects Model” on page 8-21
- “F Statistics for Models with Random Effects” on page 8-22
- “Variance Components” on page 8-24

Introduction to ANOVA with Random Effects. In an ordinary ANOVA model, each grouping variable represents a fixed factor. The levels of that factor are a fixed set of values. Your goal is to determine whether different factor levels lead to different response values. This section presents an example that shows how to use anovan to fit models where a factor’s levels represent a random selection from a larger (infinite) set of possible levels.

Setting Up the Model. To set up the example, first load the data, which is stored in a 6-by-3 matrix, `mileage`.

```
load mileage
```

The `anova2` function works only with balanced data, and it infers the values of the grouping variables from the row and column numbers of the input matrix. The `anovan` function, on the other hand, requires you to explicitly create vectors of grouping variable values. To create these vectors, do the following steps:

- 1 Create an array indicating the factory for each value in `mileage`. This array is 1 for the first column, 2 for the second, and 3 for the third.

```
factory = repmat(1:3,6,1);
```

- 2 Create an array indicating the car model for each mileage value. This array is 1 for the first three rows of `mileage`, and 2 for the remaining three rows.

```
carmod = [ones(3,3); 2*ones(3,3)];
```

- 3 Turn these matrices into vectors and display them.

```
mileage = mileage(:);  
factory = factory(:);  
carmod = carmod(:);  
[mileage factory carmod]
```

```
ans =
```

```
33.3000    1.0000    1.0000  
33.4000    1.0000    1.0000  
32.9000    1.0000    1.0000  
32.6000    1.0000    2.0000  
32.5000    1.0000    2.0000  
33.0000    1.0000    2.0000  
34.5000    2.0000    1.0000  
34.8000    2.0000    1.0000  
33.8000    2.0000    1.0000  
33.4000    2.0000    2.0000  
33.7000    2.0000    2.0000
```


33.9000	2.0000	2.0000
37.4000	3.0000	1.0000
36.8000	3.0000	1.0000
37.6000	3.0000	1.0000
36.6000	3.0000	2.0000
37.0000	3.0000	2.0000
36.7000	3.0000	2.0000

Fitting a Random Effects Model. Continuing the example from the preceding section, suppose you are studying a few factories but you want information about what would happen if you build these same car models in a different factory—either one that you already have or another that you might construct. To get this information, fit the analysis of variance model, specifying a model that includes an interaction term and that the factory factor is random.

```
[pvals,tbl,stats] = anovan(mileage, {factory carmod}, ...
    'model',2, 'random',1,'varnames',{'Factory' 'Car Model'});
```

Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Factory	53.3511	2	26.6756	1333.78	0.0007
Car Model	1.445	1	1.445	72.25	0.0136
Factory*Car Model	0.04	2	0.02	0.18	0.8411
Error	1.3667	12	0.1139		
Total	56.2028	17			

Constrained (Type III) sums of squares.

In the fixed effects version of this fit, which you get by omitting the inputs 'random', 1 in the preceding code, the effect of car model is significant, with a p value of 0.0039. But in this example, which takes into account the random variation of the effect of the variable 'Car Model' from one factory to another, the effect is still significant, but with a higher p value of 0.0136.

F Statistics for Models with Random Effects. The F statistic in a model having random effects is defined differently than in a model having all fixed effects. In the fixed effects model, you compute the F statistic for any term by taking the ratio of the mean square for that term with the mean square for error. In a random effects model, however, some F statistics use a different mean square in the denominator.

In the example described in “Setting Up the Model” on page 8-20, the effect of the variable 'Factory' could vary across car models. In this case, the interaction mean square takes the place of the error mean square in the F statistic. The F statistic for factory is:

$$F = 26.6756 / 0.02$$

$$F =$$

$$1333.78$$

The degrees of freedom for the statistic are the degrees of freedom for the numerator (2) and denominator (2) mean squares. Therefore the p value for the statistic is:

$$pval = 1 - fcdf(F,2,2)$$

$$pval =$$

$$7.4919e-04$$

With random effects, the expected value of each mean square depends not only on the variance of the error term, but also on the variances contributed by the random effects. You can see these dependencies by writing the expected values as linear combinations of contributions from the various model terms. To find the coefficients of these linear combinations, enter `stats.ems`, which returns the `ems` field of the `stats` structure:

```
stats.ems
```

```
ans =
```

```
6.0000    0.0000    3.0000    1.0000
0.0000    9.0000    3.0000    1.0000
```

```

0.0000    0.0000    3.0000    1.0000
      0          0          0    1.0000

```

To see text representations of the linear combinations, enter

```
stats.txtems
```

```
ans =
```

```

'6*V(Factory)+3*V(Factory*Car Model)+V(Error) '
'9*Q(Car Model)+3*V(Factory*Car Model)+V(Error) '
'3*V(Factory*Car Model)+V(Error) '
'V(Error) '

```

The expected value for the mean square due to car model (second term) includes contributions from a quadratic function of the car model effects, plus three times the variance of the interaction term's effect, plus the variance of the error term. Notice that if the car model effects were all zero, the expression would reduce to the expected mean square for the third term (the interaction term). That is why the F statistic for the car model effect uses the interaction mean square in the denominator.

In some cases there is no single term whose expected value matches the one required for the denominator of the F statistic. In that case, the denominator is a linear combination of mean squares. The `stats` structure contains fields giving the definitions of the denominators for each F statistic. The `txtdenom` field, `stats.txtdenom`, gives a text representation, and the `denom` field gives a matrix that defines a linear combination of the variances of terms in the model. For balanced models like this one, the `denom` matrix, `stats.denom`, contains zeros and ones, because the denominator is just a single term's mean square:

```
stats.txtdenom
```

```
ans =
```

```

'MS(Factory*Car Model) '
'MS(Factory*Car Model) '
'MS(Error) '

```

```
stats.denom
```

```
ans =  
  
-0.0000    1.0000    0.0000  
 0.0000    1.0000   -0.0000  
 0.0000         0    1.0000
```

Variance Components. For the model described in “Setting Up the Model” on page 8-20, consider the mileage for a particular car of a particular model made at a random factory. The variance of that car is the sum of components, or contributions, one from each of the random terms.

```
stats.rtnames  
  
ans =  
  
  'Factory'  
  'Factory*Car Model'  
  'Error'
```

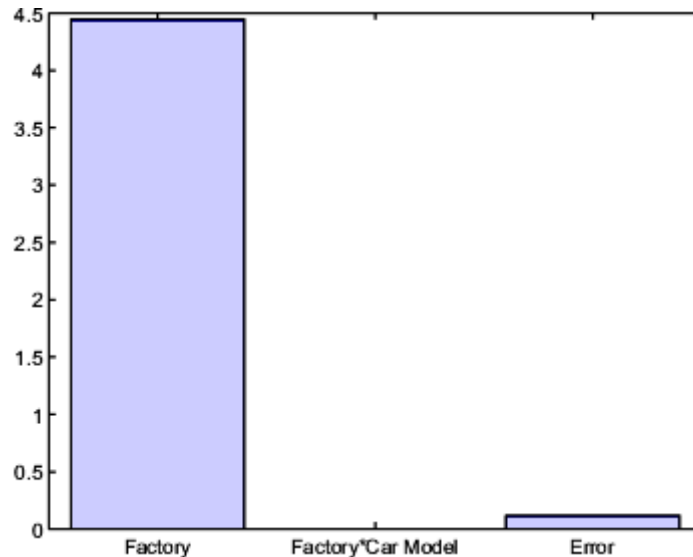
You do not know those variances, but you can estimate them from the data. Recall that the `ems` field of the `stats` structure expresses the expected value of each term’s mean square as a linear combination of unknown variances for random terms, and unknown quadratic forms for fixed terms. If you take the expected mean square expressions for the random terms, and equate those expected values to the computed mean squares, you get a system of equations that you can solve for the unknown variances. These solutions are the variance component estimates. The `varest` field contains a variance component estimate for each term. The `rtnames` field contains the names of the random terms.

```
stats.varest  
  
ans =  
  
  4.4426  
 -0.0313  
  0.1139
```

Under some conditions, the variability attributed to a term is unusually low, and that term’s variance component estimate is negative. In those cases it

is common to set the estimate to zero, which you might do, for example, to create a bar graph of the components.

```
bar(max(0,stats.varest))
set(gca,'xtick',1:3,'xticklabel',stats.rtnames)
```



You can also compute confidence bounds for the variance estimate. The `anovan` function does this by computing confidence bounds for the variance expected mean squares, and finding lower and upper limits on each variance component containing all of these bounds. This procedure leads to a set of bounds that is conservative for balanced data. (That is, 95% confidence bounds will have a probability of at least 95% of containing the true variances if the number of observations for each combination of grouping variables is the same.) For unbalanced data, these are approximations that are not guaranteed to be conservative.

```
[{'Term' 'Estimate' 'Lower' 'Upper'};
 stats.rtnames, num2cell([stats.varest stats.varci])]
```

```
ans =
```

```
    'Term'                'Estimate'    'Lower'    'Upper'
```

```

'Factory'          [  4.4426]    [1.0736]    [175.6038]
'Factory*Car Model' [ -0.0313]    [   NaN]    [   NaN]
'Error'           [  0.1139]    [0.0586]    [  0.3103]

```

Other ANOVA Models

The `anovan` function also has arguments that enable you to specify two other types of model terms. First, the `'nested'` argument specifies a matrix that indicates which factors are nested within other factors. A nested factor is one that takes different values within each level its nested factor.

For example, the mileage data from the previous section assumed that the two car models produced in each factory were the same. Suppose instead, each factory produced two distinct car models for a total of six car models, and we numbered them 1 and 2 for each factory for convenience. Then, the car model is nested in factory. A more accurate and less ambiguous numbering of car model would be as follows:

Factory	Car Model
1	1
1	2
2	3
2	4
3	5
3	6

However, it is common with nested models to number the nested factor the same way in each nested factor.

Second, the `'continuous'` argument specifies that some factors are to be treated as continuous variables. The remaining factors are categorical variables. Although the `anovan` function can fit models with multiple continuous and categorical predictors, the simplest model that combines one predictor of each type is known as an *analysis of covariance* model. The next section describes a specialized tool for fitting this model.

Analysis of Covariance

- “Introduction to Analysis of Covariance” on page 8-27
- “Analysis of Covariance Tool” on page 8-27
- “Confidence Bounds” on page 8-31
- “Multiple Comparisons” on page 8-34

Introduction to Analysis of Covariance

Analysis of covariance is a technique for analyzing grouped data having a response (y , the variable to be predicted) and a predictor (x , the variable used to do the prediction). Using analysis of covariance, you can model y as a linear function of x , with the coefficients of the line possibly varying from group to group.

Analysis of Covariance Tool

The `aocool` function opens an interactive graphical environment for fitting and prediction with analysis of covariance (ANOCOVA) models. It fits the following models for the i th group:

Same mean	$y = a + \varepsilon$
Separate means	$y = (a + a_i) + \varepsilon$
Same line	$y = a + \beta x + \varepsilon$
Parallel lines	$y = (a + a_i) + \beta x + \varepsilon$
Separate lines	$y = (a + a_i) + (\beta + \beta_i)x + \varepsilon$

For example, in the parallel lines model the intercept varies from one group to the next, but the slope is the same for each group. In the same mean model, there is a common intercept and no slope. In order to make the group coefficients well determined, the tool imposes the constraints

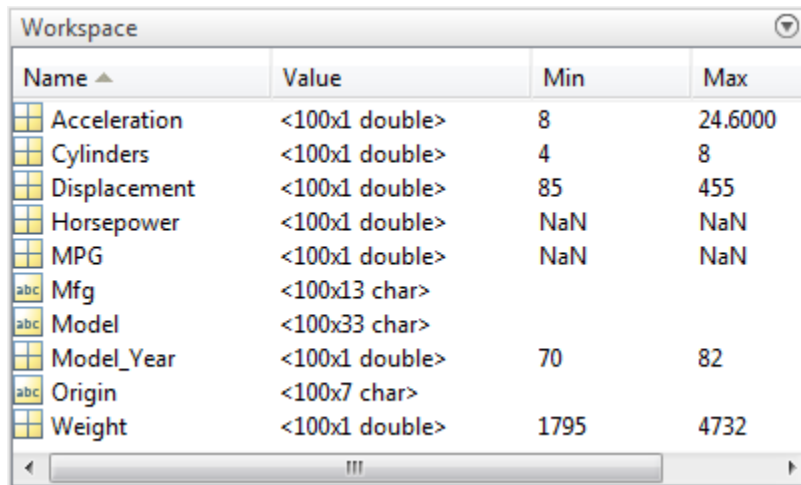
$$\sum \alpha_j = \sum \beta_j = 0$$

The following steps describe the use of `aocool`.

- 1 Load the data.** The Statistics Toolbox data set `carsmall.mat` contains information on cars from the years 1970, 1976, and 1982. This example studies the relationship between the weight of a car and its mileage, and whether this relationship has changed over the years. To start the demonstration, load the data set.

```
load carsmall
```

The Workspace Browser shows the variables in the data set.



Name ^	Value	Min	Max
Acceleration	<100x1 double>	8	24.6000
Cylinders	<100x1 double>	4	8
Displacement	<100x1 double>	85	455
Horsepower	<100x1 double>	NaN	NaN
MPG	<100x1 double>	NaN	NaN
Mfg	<100x13 char>		
Model	<100x33 char>		
Model_Year	<100x1 double>	70	82
Origin	<100x7 char>		
Weight	<100x1 double>	1795	4732

You can also use `aoctool` with your own data.

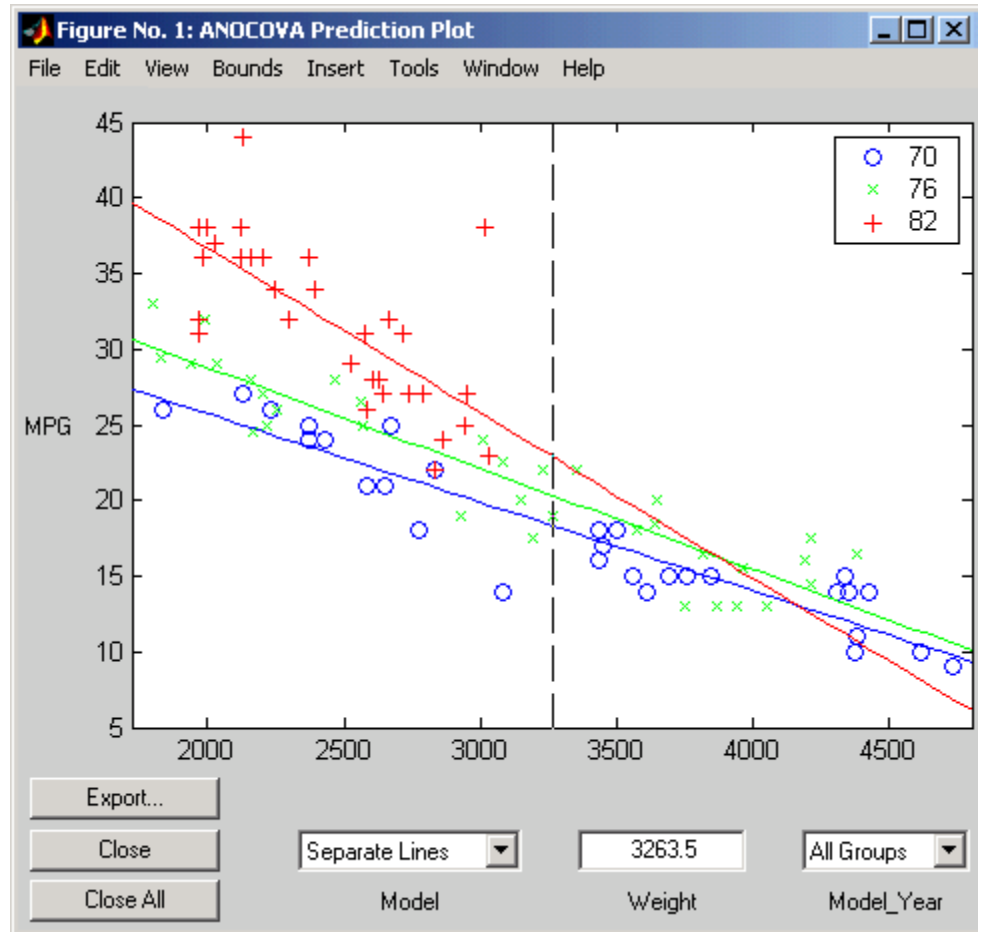
- 2 Start the tool.** The following command calls `aoctool` to fit a separate line to the column vectors `Weight` and `MPG` for each of the three model group defined in `Model_Year`. The initial fit models the y variable, `MPG`, as a linear function of the x variable, `Weight`.

```
[h,atab,ctab,stats] = aoctool(Weight,MPG,Model_Year);
```

See the `aoctool` function reference page for detailed information about calling `aoctool`.

- 3 Examine the output.** The graphical output consists of a main window with a plot, a table of coefficient estimates, and an analysis of variance table. In the plot, each `Model_Year` group has a separate line. The data

points for each group are coded with the same color and symbol, and the fit for each group has the same color as the data points.



The coefficients of the three lines appear in the figure titled ANCOVA Coefficients. You can see that the slopes are roughly -0.0078 , with a small deviation for each group:

- Model year 1970: $y = (45.9798 - 8.5805) + (-0.0078 + 0.002)x + \varepsilon$
- Model year 1976: $y = (45.9798 - 3.8902) + (-0.0078 + 0.0011)x + \varepsilon$

- Model year 1982: $y = (45.9798 + 12.4707) + (-0.0078 - 0.0031)x + \varepsilon$

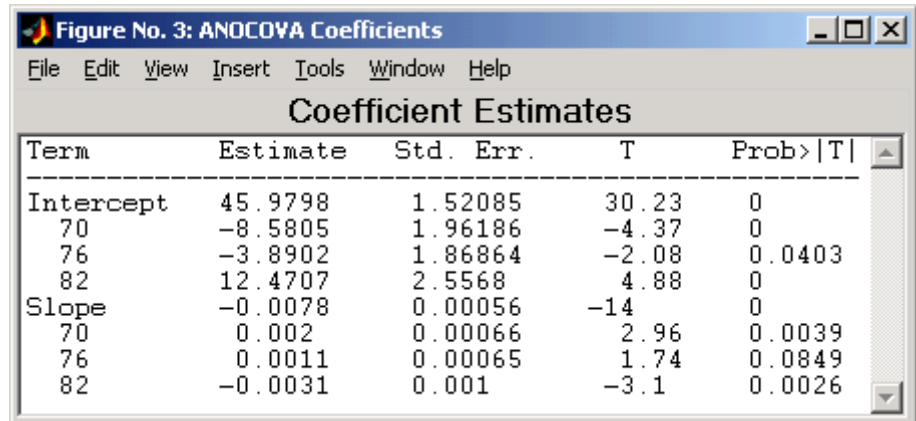


Figure No. 3: ANCOVA Coefficients

Term	Estimate	Std. Err.	T	Prob> T
Intercept	45.9798	1.52085	30.23	0
70	-8.5805	1.96186	-4.37	0
76	-3.8902	1.86864	-2.08	0.0403
82	12.4707	2.5568	4.88	0
Slope	-0.0078	0.00056	-14	0
70	0.002	0.00066	2.96	0.0039
76	0.0011	0.00065	1.74	0.0849
82	-0.0031	0.001	-3.1	0.0026

Because the three fitted lines have slopes that are roughly similar, you may wonder if they really are the same. The `Model_Year*Weight` interaction expresses the difference in slopes, and the ANOVA table shows a test for the significance of this term. With an F statistic of 5.23 and a p value of 0.0072, the slopes are significantly different.

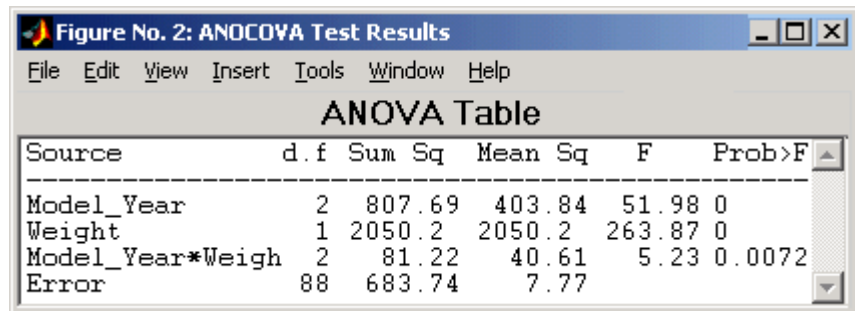
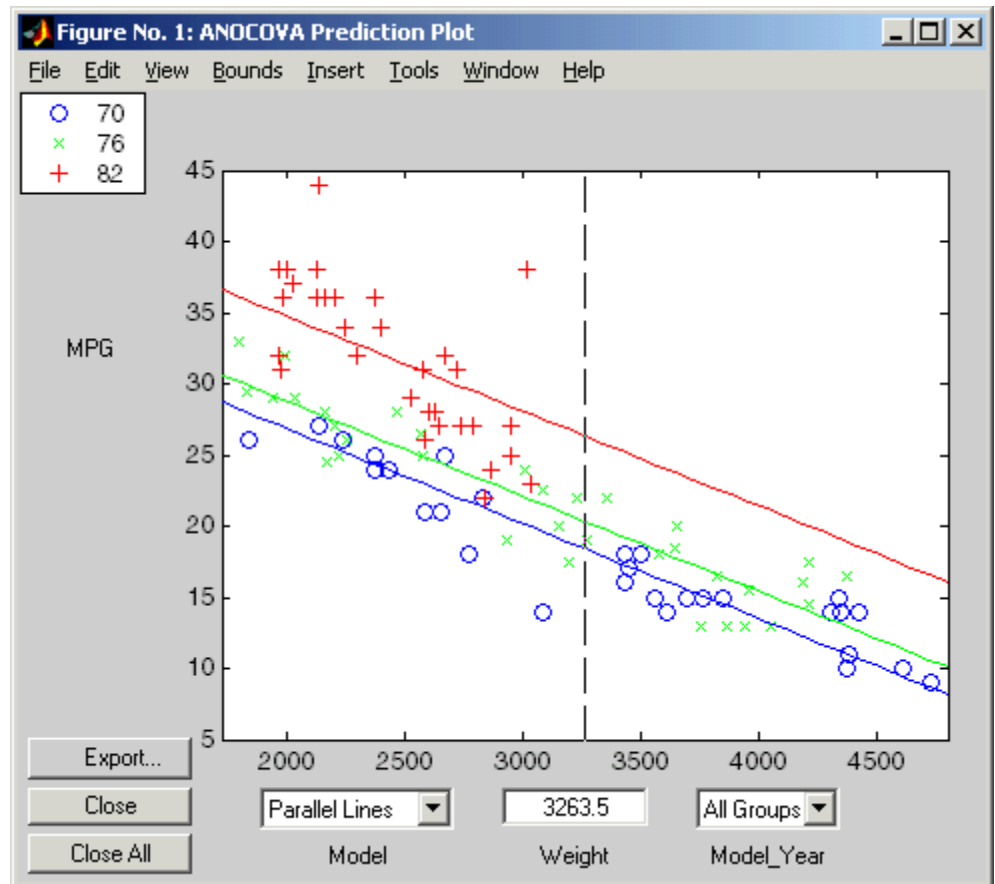


Figure No. 2: ANCOVA Test Results

Source	d.f	Sum Sq	Mean Sq	F	Prob>F
Model_Year	2	807.69	403.84	51.98	0
Weight	1	2050.2	2050.2	263.87	0
Model_Year*Weigh	2	81.22	40.61	5.23	0.0072
Error	88	683.74	7.77		

- 4 Constrain the slopes to be the same.** To examine the fits when the slopes are constrained to be the same, return to the ANCOVA Prediction Plot window and use the **Model** pop-up menu to select a **Parallel Lines** model. The window updates to show the following graph.

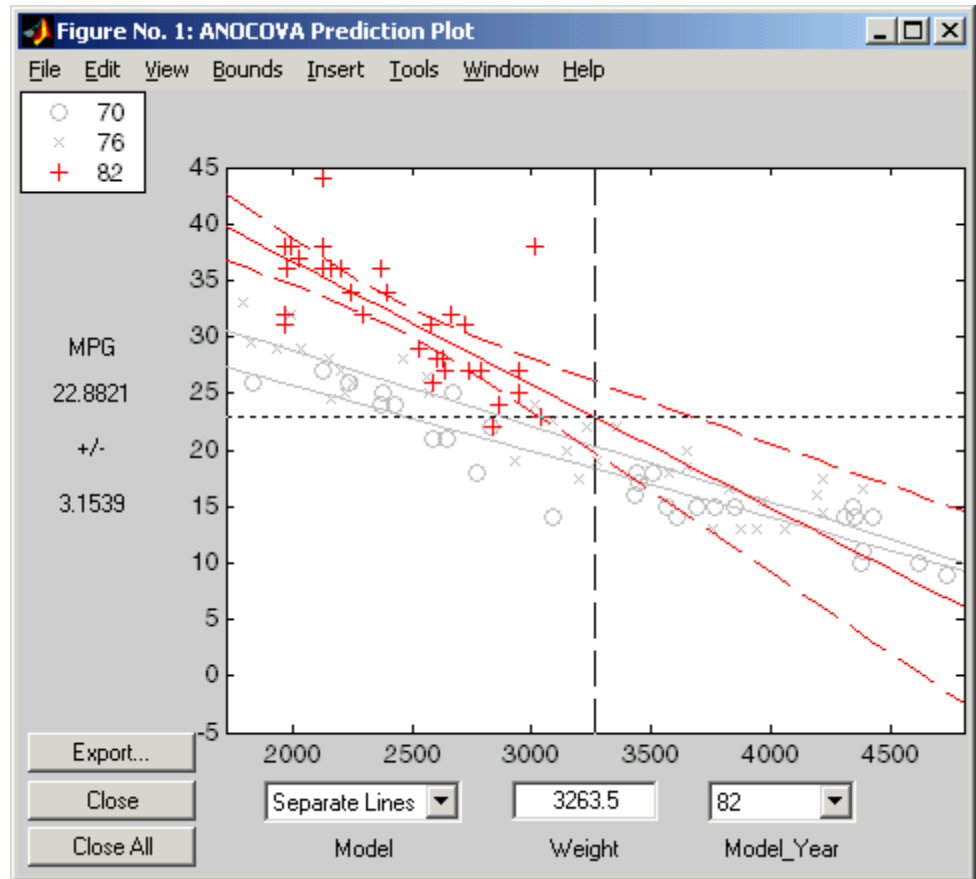


Though this fit looks reasonable, it is significantly worse than the Separate Lines model. Use the **Model** pop-up menu again to return to the original model.

Confidence Bounds

The example in “Analysis of Covariance Tool” on page 8-27 provides estimates of the relationship between MPG and Weight for each Model_Year, but how accurate are these estimates? To find out, you can superimpose confidence bounds on the fits by examining them one group at a time.

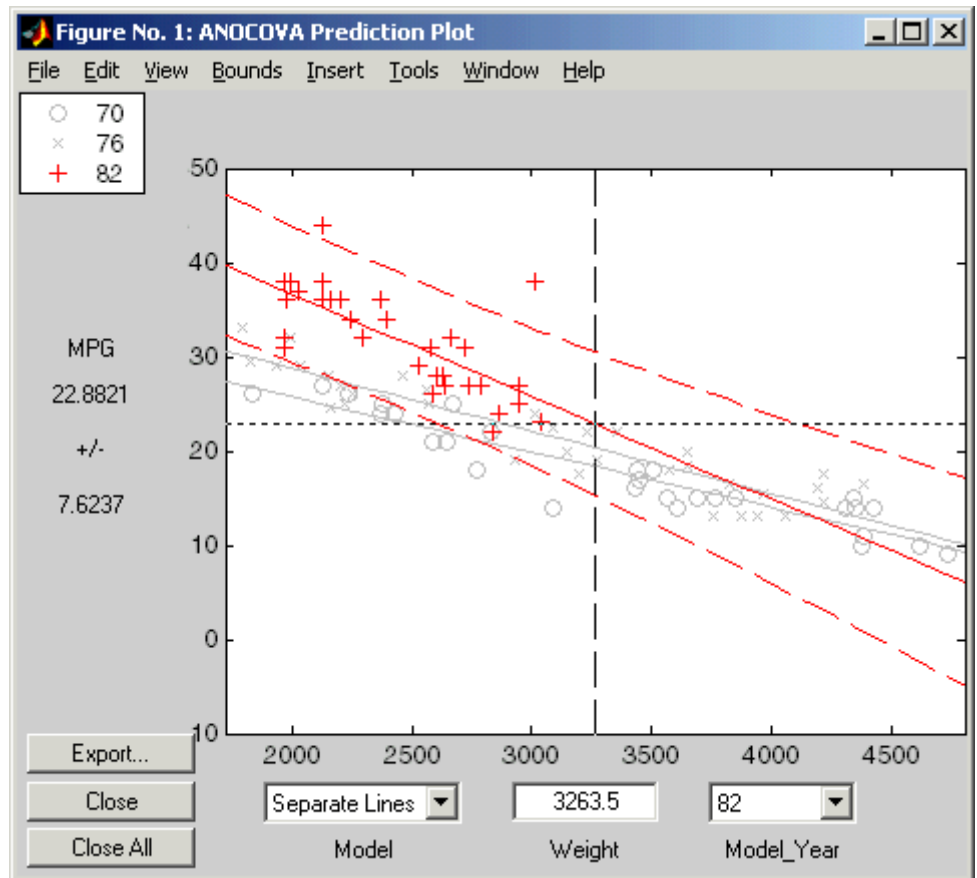
- 1 In the **Model_Year** menu at the lower right of the figure, change the setting from All Groups to 82. The data and fits for the other groups are dimmed, and confidence bounds appear around the 82 fit.



The dashed lines form an envelope around the fitted line for model year 82. Under the assumption that the true relationship is linear, these bounds provide a 95% confidence region for the true line. Note that the fits for the other model years are well outside these confidence bounds for Weight values between 2000 and 3000.

- 2 Sometimes it is more valuable to be able to predict the response value for a new observation, not just estimate the average response value. Use the

aoctool function **Bounds** menu to change the definition of the confidence bounds from Line to Observation. The resulting wider intervals reflect the uncertainty in the parameter estimates as well as the randomness of a new observation.



Like the polytool function, the aoctool function has cross hairs that you can use to manipulate the Weight and watch the estimate and confidence bounds along the y-axis update. These values appear only when a single group is selected, not when All Groups is selected.

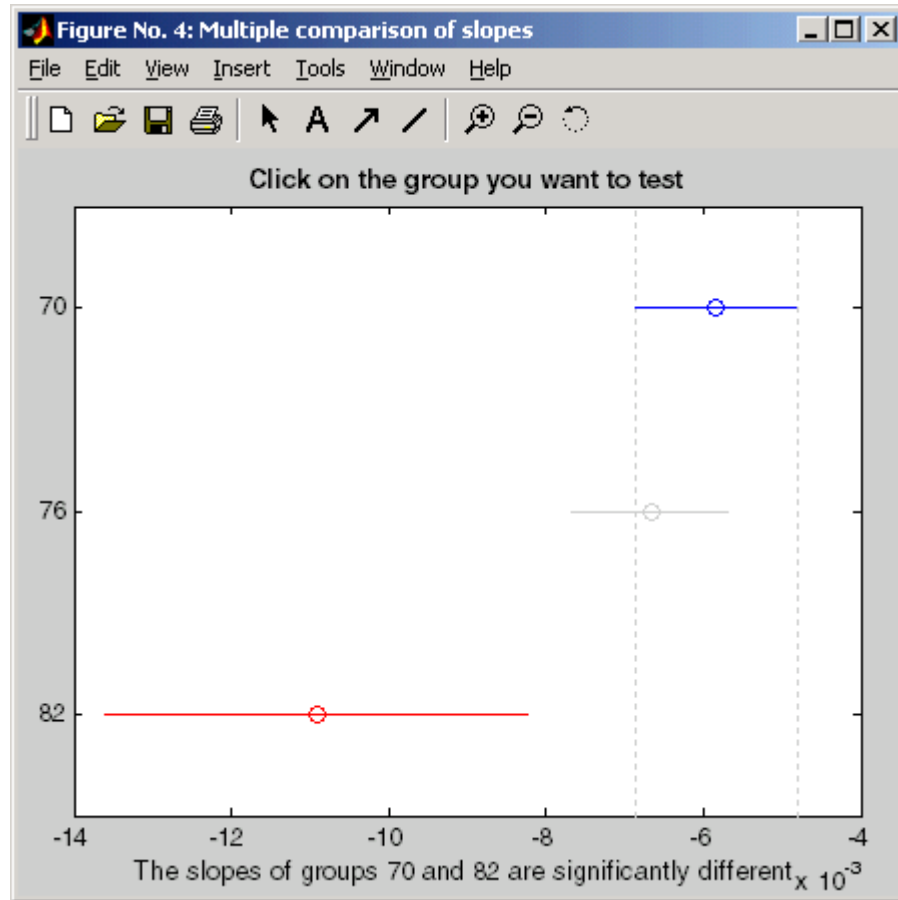
Multiple Comparisons

You can perform a multiple comparison test by using the `stats` output structure from `aocool` as input to the `multcompare` function. The `multcompare` function can test either slopes, intercepts, or population marginal means (the predicted MPG of the mean weight for each group). The example in “Analysis of Covariance Tool” on page 8-27 shows that the slopes are not all the same, but could it be that two are the same and only the other one is different? You can test that hypothesis.

```
multcompare(stats,0.05,'on',' ','s')
```

```
ans =  
    1.0000    2.0000   -0.0012    0.0008    0.0029  
    1.0000    3.0000    0.0013    0.0051    0.0088  
    2.0000    3.0000    0.0005    0.0042    0.0079
```

This matrix shows that the estimated difference between the intercepts of groups 1 and 2 (1970 and 1976) is 0.0008, and a confidence interval for the difference is $[-0.0012, 0.0029]$. There is no significant difference between the two. There are significant differences, however, between the intercept for 1982 and each of the other two. The graph shows the same information.



Note that the `stats` structure was created in the initial call to the `aocool` function, so it is based on the initial model fit (typically a separate-lines model). If you change the model interactively and want to base your multiple comparisons on the new model, you need to run `aocool` again to get another `stats` structure, this time specifying your new model as the initial model.

Nonparametric Methods

- “Introduction to Nonparametric Methods” on page 8-36

- “Kruskal-Wallis Test” on page 8-36
- “Friedman’s Test” on page 8-37

Introduction to Nonparametric Methods

Statistics Toolbox functions include nonparametric versions of one-way and two-way analysis of variance. Unlike classical tests, nonparametric tests make only mild assumptions about the data, and are appropriate when the distribution of the data is non-normal. On the other hand, they are less powerful than classical methods for normally distributed data.

Both of the nonparametric functions described here will return a `stats` structure that can be used as an input to the `multcompare` function for multiple comparisons.

Kruskal-Wallis Test

The example “Example: One-Way ANOVA” on page 8-4 uses one-way analysis of variance to determine if the bacteria counts of milk varied from shipment to shipment. The one-way analysis rests on the assumption that the measurements are independent, and that each has a normal distribution with a common variance and with a mean that was constant in each column. You can conclude that the column means were not all the same. The following example repeats that analysis using a nonparametric procedure.

The Kruskal-Wallis test is a nonparametric version of one-way analysis of variance. The assumption behind this test is that the measurements come from a continuous distribution, but not necessarily a normal distribution. The test is based on an analysis of variance using the ranks of the data values, not the data values themselves. Output includes a table similar to an ANOVA table, and a box plot.

You can run this test as follows:

```
load hogg

p = kruskalwallis(hogg)
p =
    0.0020
```


The low p value means the Kruskal-Wallis test results agree with the one-way analysis of variance results.

Friedman's Test

“Example: Two-Way ANOVA” on page 8-10 uses two-way analysis of variance to study the effect of car model and factory on car mileage. The example tests whether either of these factors has a significant effect on mileage, and whether there is an interaction between these factors. The conclusion of the example is there is no interaction, but that each individual factor has a significant effect. The next example examines whether a nonparametric analysis leads to the same conclusion.

Friedman's test is a nonparametric test for data having a two-way layout (data grouped by two categorical factors). Unlike two-way analysis of variance, Friedman's test does not treat the two factors symmetrically and it does not test for an interaction between them. Instead, it is a test for whether the columns are different after adjusting for possible row differences. The test is based on an analysis of variance using the ranks of the data across categories of the row factor. Output includes a table similar to an ANOVA table.

You can run Friedman's test as follows.

```
load mileage
p = friedman(mileage,3)
p =
    7.4659e-004
```

Recall the classical analysis of variance gave a p value to test column effects, row effects, and interaction effects. This p value is for column effects. Using either this p value or the p value from ANOVA ($p < 0.0001$), you conclude that there are significant column effects.

In order to test for row effects, you need to rearrange the data to swap the roles of the rows in columns. For a data matrix x with no replications, you could simply transpose the data and type

```
p = friedman(x')
```

With replicated data it is slightly more complicated. A simple way is to transform the matrix into a three-dimensional array with the first dimension

representing the replicates, swapping the other two dimensions, and restoring the two-dimensional shape.

```
x = reshape(mileage, [3 2 3]);
x = permute(x,[1 3 2]);
x = reshape(x,[9 2])
x =
  33.3000    32.6000
  33.4000    32.5000
  32.9000    33.0000
  34.5000    33.4000
  34.8000    33.7000
  33.8000    33.9000
  37.4000    36.6000
  36.8000    37.0000
  37.6000    36.7000
```

```
friedman(x,3)
ans =
    0.0082
```

Again, the conclusion is similar to that of the classical analysis of variance. Both this p value and the one from ANOVA ($p = 0.0039$) lead you to conclude that there are significant row effects.

You cannot use Friedman's test to test for interactions between the row and column factors.

MANOVA

In this section...

“Introduction to MANOVA” on page 8-39

“ANOVA with Multiple Responses” on page 8-39

Introduction to MANOVA

The analysis of variance technique in “Example: One-Way ANOVA” on page 8-4 takes a set of grouped data and determine whether the mean of a variable differs significantly among groups. Often there are multiple response variables, and you are interested in determining whether the entire set of means is different from one group to the next. There is a multivariate version of analysis of variance that can address the problem.

ANOVA with Multiple Responses

The carsmall data set has measurements on a variety of car models from the years 1970, 1976, and 1982. Suppose you are interested in whether the characteristics of the cars have changed over time.

First, load the data.

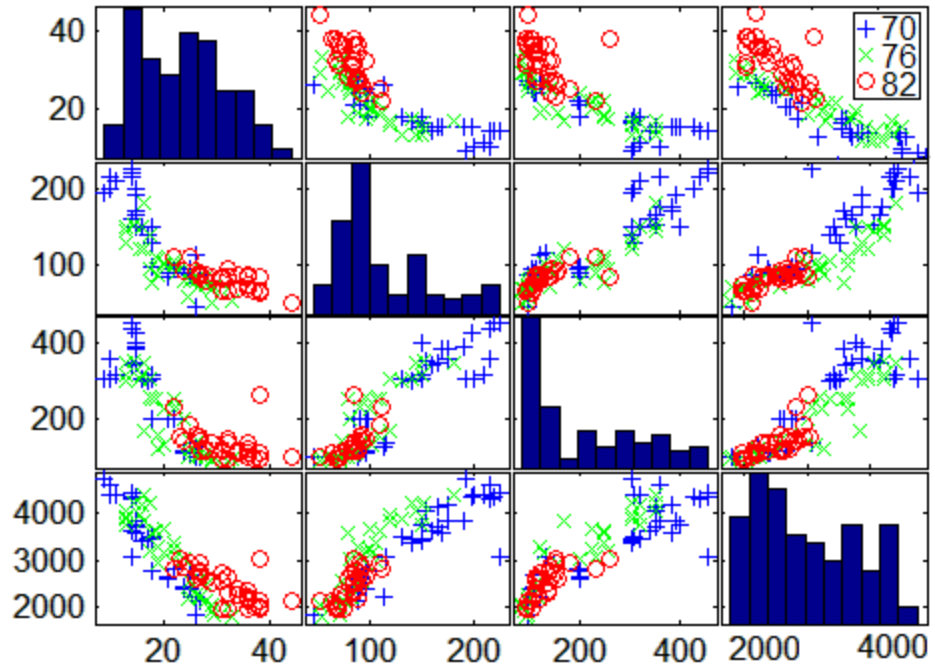
```
load carsmall
whos
```

Name	Size	Bytes	Class
Acceleration	100x1	800	double array
Cylinders	100x1	800	double array
Displacement	100x1	800	double array
Horsepower	100x1	800	double array
MPG	100x1	800	double array
Model	100x36	7200	char array
Model_Year	100x1	800	double array
Origin	100x7	1400	char array
Weight	100x1	800	double array

Four of these variables (Acceleration, Displacement, Horsepower, and MPG) are continuous measurements on individual car models. The variable

Model_Year indicates the year in which the car was made. You can create a grouped plot matrix of these variables using the `gplotmatrix` function.

```
x = [MPG Horsepower Displacement Weight];
gplotmatrix(x,[],Model_Year,[],'+xo')
```



(When the second argument of `gplotmatrix` is empty, the function graphs the columns of the `x` argument against each other, and places histograms along the diagonals. The empty fourth argument produces a graph with the default colors. The fifth argument controls the symbols used to distinguish between groups.)

It appears the cars do differ from year to year. The upper right plot, for example, is a graph of MPG versus Weight. The 1982 cars appear to have higher mileage than the older cars, and they appear to weigh less on average. But as a group, are the three years significantly different from one another? The `manova1` function can answer that question.

```
[d,p,stats] = manova1(x,Model_Year)
```

```
d =
    2
p =
    1.0e-006 *
    0
    0.1141
stats =
    W: [4x4 double]
    B: [4x4 double]
    T: [4x4 double]
    dfW: 90
    dfB: 2
    dfT: 92
    lambda: [2x1 double]
    chisq: [2x1 double]
    chisqdf: [2x1 double]
    eigenval: [4x1 double]
    eigenvac: [4x4 double]
    canon: [100x4 double]
    mdist: [100x1 double]
    gmdist: [3x3 double]
```

The `manova1` function produces three outputs:

- The first output, `d`, is an estimate of the dimension of the group means. If the means were all the same, the dimension would be 0, indicating that the means are at the same point. If the means differed but fell along a line, the dimension would be 1. In the example the dimension is 2, indicating that the group means fall in a plane but not along a line. This is the largest possible dimension for the means of three groups.
- The second output, `p`, is a vector of p -values for a sequence of tests. The first p value tests whether the dimension is 0, the next whether the dimension is 1, and so on. In this case both p -values are small. That's why the estimated dimension is 2.
- The third output, `stats`, is a structure containing several fields, described in the following section.

The Fields of the stats Structure

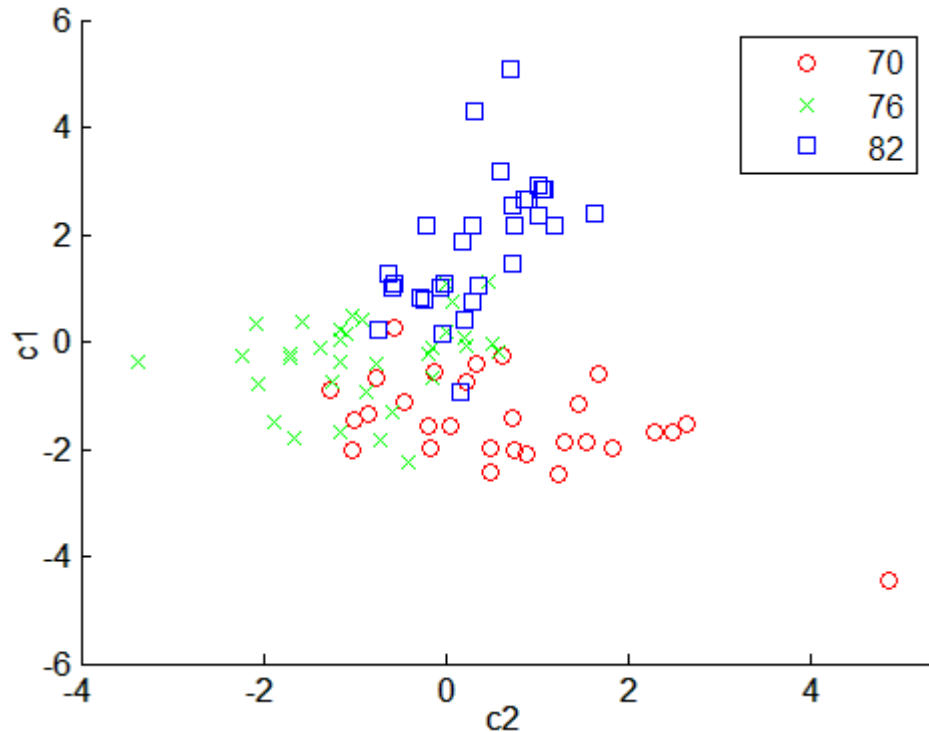
The `W`, `B`, and `T` fields are matrix analogs to the within, between, and total sums of squares in ordinary one-way analysis of variance. The next three fields are the degrees of freedom for these matrices. Fields `lambda`, `chisq`, and `chisqdf` are the ingredients of the test for the dimensionality of the group means. (The p -values for these tests are the first output argument of `manova1`.)

The next three fields are used to do a canonical analysis. Recall that in principal components analysis (“Principal Component Analysis (PCA)” on page 10-31) you look for the combination of the original variables that has the largest possible variation. In multivariate analysis of variance, you instead look for the linear combination of the original variables that has the largest separation between groups. It is the single variable that would give the most significant result in a univariate one-way analysis of variance. Having found that combination, you next look for the combination with the second highest separation, and so on.

The `eigenvec` field is a matrix that defines the coefficients of the linear combinations of the original variables. The `eigenval` field is a vector measuring the ratio of the between-group variance to the within-group variance for the corresponding linear combination. The `canon` field is a matrix of the canonical variable values. Each column is a linear combination of the mean-centered original variables, using coefficients from the `eigenvec` matrix.

A grouped scatter plot of the first two canonical variables shows more separation between groups than a grouped scatter plot of any pair of original variables. In this example it shows three clouds of points, overlapping but with distinct centers. One point in the bottom right sits apart from the others. By using the `gname` function, you can see that this is the 20th point.

```
c1 = stats.canon(:,1);
c2 = stats.canon(:,2);
gscatter(c2,c1,Model_Year,[],'oxs')
gname
```



Roughly speaking, the first canonical variable, c_1 , separates the 1982 cars (which have high values of c_1) from the older cars. The second canonical variable, c_2 , reveals some separation between the 1970 and 1976 cars.

The final two fields of the `stats` structure are Mahalanobis distances. The `mdist` field measures the distance from each point to its group mean. Points with large values may be outliers. In this data set, the largest outlier is the one in the scatter plot, the Buick Estate station wagon. (Note that you could have supplied the model name to the `gname` function above if you wanted to label the point with its model name rather than its row number.)

```
max(stats.mdist)
ans =
    31.5273
find(stats.mdist == ans)
ans =
```

```
20
Model(20,:)
ans =
    buick_estate_wagon_(sw)
```

The `gmdist` field measures the distances between each pair of group means. The following commands examine the group means and their distances:

```
grpstats(x, Model_Year)
ans =
    1.0e+003 *
         0.0177    0.1489    0.2869    3.4413
         0.0216    0.1011    0.1978    3.0787
         0.0317    0.0815    0.1289    2.4535
stats.gmdist
ans =
         0    3.8277    11.1106
    3.8277         0    6.1374
    11.1106    6.1374         0
```

As might be expected, the multivariate distance between the extreme years 1970 and 1982 (11.1) is larger than the difference between more closely spaced years (3.8 and 6.1). This is consistent with the scatter plots, where the points seem to follow a progression as the year changes from 1970 through 1976 to 1982. If you had more groups, you might find it instructive to use the `manovacluster` function to draw a diagram that presents clusters of the groups, formed using the distances between their means.

Parametric Regression Analysis

- “Parametric Regression Analysis” on page 9-2
- “Linear Regression” on page 9-7
- “Regression Using Dataset Arrays” on page 9-47
- “Linear Regression with Interaction Effects” on page 9-50
- “Interpret Linear Regression Results” on page 9-60
- “Linear Regression Output and Diagnostic Statistics” on page 9-68
- “Stepwise Regression” on page 9-108
- “Robust Regression — Reduce Outlier Effects” on page 9-113
- “Ridge Regression” on page 9-116
- “Lasso and Elastic Net” on page 9-120
- “Partial Least Squares” on page 9-134
- “Multivariate Regression” on page 9-140
- “Generalized Linear Models” on page 9-141
- “Lasso Regularization of Generalized Linear Models” on page 9-176
- “Nonlinear Regression” on page 9-196
- “Mixed-Effects Models” on page 9-217
- “Pitfalls in Fitting Nonlinear Models by Transforming to Linearity” on page 9-253

Parametric Regression Analysis

In this section...

“What Is Parametric Regression?” on page 9-2

“Choose a Regression Function” on page 9-2

“Update Legacy Code with New Fitting Methods” on page 9-3

What Is Parametric Regression?

Regression is the process of fitting models to data. The models must have numerical responses. For models with categorical responses, see “Parametric Classification” on page 12-2 or “Supervised Learning (Machine Learning) Workflow and Algorithms” on page 13-2. The regression process depends on the model. If a model is parametric, regression estimates the parameters from the data. If a model is linear in the parameters, estimation is based on methods from linear algebra that minimize the norm of a residual vector. If a model is nonlinear in the parameters, estimation is based on search methods from optimization that minimize the norm of a residual vector.

Choose a Regression Function

You have:	You want:	Use this:
Continuous or categorical predictors, continuous response, linear model	Fitted model coefficients	<code>LinearModel.fit</code> See “Linear Regression” on page 9-7.
Continuous or categorical predictors, continuous response, linear model of unknown complexity	Fitted model and fitted coefficients	<code>LinearModel.stepwise</code> See “Stepwise Regression” on page 9-108.
Continuous or categorical predictors, response possibly with restrictions such as nonnegative or integer-valued, generalized linear model	Fitted generalized linear model coefficients	<code>GeneralizedLinearModel.fit</code> or <code>GeneralizedLinearModel.stepwise</code> See “Generalized Linear Models” on page 9-141.

You have:	You want:	Use this:
Continuous predictors with a continuous nonlinear response, parametrized nonlinear model	Fitted nonlinear model coefficients	<code>NonLinearModel.fit</code> See “Nonlinear Regression” on page 9-196.
Continuous predictors, continuous response, linear model	Set of models from ridge, lasso, or elastic net regression	<code>lasso</code> or <code>ridge</code> See “Lasso and Elastic Net” on page 9-120 or “Ridge Regression” on page 9-116.
Correlated continuous predictors, continuous response, linear model	Fitted model and fitted coefficients	<code>plsregress</code> See “Partial Least Squares” on page 9-134.
Continuous or categorical predictors, continuous response, unknown model	Nonparametric model	<code>RegressionTree.fit</code> or <code>fitensemble</code> See “Classification Trees and Regression Trees” on page 13-30 or “Ensemble Methods” on page 13-54.
Categorical predictors only	ANOVA	<code>anova</code> , <code>anova1</code> , <code>anova2</code> , <code>anovan</code>
Continuous predictors, multivariable response, linear model	Fitted multivariate regression model coefficients	<code>mvregress</code>
Continuous predictors, continuous response, mixed-effects model	Fitted mixed-effects model coefficients	<code>nlmefit</code> or <code>nlmefitsa</code> See “Mixed-Effects Models” on page 9-217.

Update Legacy Code with New Fitting Methods

There are several Statistics Toolbox functions for performing regression. The following sections describe how to replace calls to older functions to new versions:

- “regress into `LinearModel.fit`” on page 9-4
- “regstats into `LinearModel.fit`” on page 9-4

- “robustfit into LinearModel.fit” on page 9-5
- “stepwisefit into LinearModel.stepwise” on page 9-5
- “glmfit into GeneralizedLinearModel.fit” on page 9-6
- “nlinfit into NonLinearModel.fit” on page 9-6

regress into LinearModel.fit

Previous Syntax.

```
[b,bint,r,rint,stats] = regress(y,X)
```

where X contains a column of ones.

Current Syntax.

```
mdl = LinearModel.fit(X,y)
```

where you do not add a column of ones to X .

Equivalent values of the previous outputs:

- b — `mdl.Coefficients.Estimate`
- $bint$ — `coefCI(mdl)`
- r — `mdl.Residuals.Raw`
- $rint$ — There is no exact equivalent. Try examining `mdl.Residuals.Studentized` to find outliers.
- $stats$ — `mdl` contains various properties that replace components of `stats`.

regstats into LinearModel.fit

Previous Syntax.

```
stats = regstats(y,X,model,whichstats)
```

Current Syntax.

```
mdl = LinearModel.fit(X,y,model)
```

Obtain statistics from the properties and methods of `mdl`. For example, see the `mdl.Diagnostics` and `mdl.Residuals` properties.

robustfit into LinearModel.fit

Previous Syntax.

```
[b,stats] = robustfit(X,y,wfun,tune,const)
```

Current Syntax.

```
mdl = LinearModel.fit(X,y,'robust','on') % bisquare
```

Or to use the *wfun* weight and the *tune* tuning parameter:

```
opt.RobustWgtFun = 'wfun';
opt.Tune = tune; % optional
mdl = LinearModel.fit(X,y,'robust',opt)
```

Obtain statistics from the properties and methods of `mdl`. For example, see the `mdl.Diagnostics` and `mdl.Residuals` properties.

stepwisefit into LinearModel.stepwise

Previous Syntax.

```
[b,se,pval,inmodel,stats,nextstep,history] = stepwisefit(X,y,Name,Value)
```

Current Syntax.

```
mdl = LinearModel.stepwise(ds,modelspec,Name,Value)
```

or

```
mdl = LinearModel.stepwise(X,y,modelspec,Name,Value)
```

Obtain statistics from the properties and methods of `mdl`. For example, see the `mdl.Diagnostics` and `mdl.Residuals` properties.

glmfit into GeneralizedLinearModel.fit

Previous Syntax.

```
[b,dev,stats] = glmfit(X,y,distr,param1,val1,...)
```

Current Syntax.

```
mdl = GeneralizedLinearModel.fit(X,y,distr,...)
```

Obtain statistics from the properties and methods of `mdl`. For example, the deviance is `mdl.Deviance`, and to compare `mdl` against a constant model, use `devianceTest(mdl)`.

nlinfit into NonLinearModel.fit

Previous Syntax.

```
[beta,r,J,COVB,mse] = nlinfit(X,y,fun,beta0,options)
```

Current Syntax.

```
mdl = NonLinearModel.fit(X,y,fun,beta0,'Options',options)
```

Equivalent values of the previous outputs:

- `beta` — `mdl.Coefficients.Estimate`
- `r` — `mdl.Residuals.Raw`
- `covb` — `mdl.CoefficientCovariance`
- `mse` — `mdl.mse`

`mdl` does not provide the Jacobian (`J`) output. The primary purpose of `J` was to pass it into `nlparci` or `nlpredci` to obtain confidence intervals for the estimated coefficients (parameters) or predictions. Obtain those confidence intervals as:

```
parci = coefCI(mdl)  
[pred,predci] = predict(mdl)
```

Linear Regression

In this section...

“What Is a Linear Regression Model?” on page 9-7

“Prepare Data” on page 9-8

“Choose a Fitting Method” on page 9-10

“Choose a Model or Range of Models” on page 9-11

“Fit Model to Data” on page 9-17

“Examine Quality and Adjust the Fitted Model” on page 9-17

“Predict or Simulate Responses to New Data” on page 9-36

“Share Fitted Models” on page 9-39

“Linear Regression Workflow” on page 9-40

What Is a Linear Regression Model?

A linear regression model is a model of the form

$$\underbrace{\begin{pmatrix} y_1 \\ \vdots \\ y_n \end{pmatrix}}_y = \underbrace{\begin{pmatrix} f_1(\mathbf{x}_1) & \cdots & f_p(\mathbf{x}_1) \\ \vdots & \ddots & \vdots \\ f_1(\mathbf{x}_n) & \cdots & f_p(\mathbf{x}_n) \end{pmatrix}}_X \underbrace{\begin{pmatrix} \beta_1 \\ \vdots \\ \beta_p \end{pmatrix}}_\beta + \underbrace{\begin{pmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_n \end{pmatrix}}_\varepsilon$$

where

- y_i is the i th scalar response.
- f_j is the j th scalar-valued function.
- \mathbf{x}_i is the i th vector input data.
- β_j is the j th scalar coefficient.
- ε_i is the i th scalar noise term.

The functions $f_j(\mathbf{x})$ can be any functions, though frequently they are vector components \mathbf{x}_j or polynomials in the components.

The model is called linear because it is linear in the coefficients β_j .

The usual assumptions on the noise terms is that the ε_i are:

- Independent of each other
- Identically distributed
- Normally distributed
- Mean zero

Under these assumptions, fitting functions calculate various statistics about the optimal coefficients β_j .

The fitted coefficients β_j minimize the mean squared difference between the prediction vector $X\beta$ and the true response vector y . Under the assumptions on the noise terms, this β also maximizes the likelihood of the prediction vector.

Prepare Data

To begin fitting a regression, put your data into a form that fitting functions expect. All regression techniques begin with input data in an array X and response data in a separate vector y , or input data in a dataset array ds and response data as a column in ds . Each row of the input data represents one observation. Each column represents one predictor (variable).

For a dataset array ds , indicate the response variable with the 'ResponseVar' name-value pair:

```
mdl = LinearModel.fit(ds, 'ResponseVar', 'BloodPressure');  
% or  
mdl = GeneralizedLinearModel.fit(ds, 'ResponseVar', 'BloodPressure');
```

The response variable is the last column by default.

You can use numeric *categorical* predictors. A categorical predictor is one that takes values from a fixed set of possibilities.

- For a numeric array X , indicate the categorical predictors using the 'Categorical' name-value pair. For example, to indicate that predictors 2 and 3 out of six are categorical:


```
mdl = LinearModel.fit(X,y,'Categorical',[2,3]);
% or
mdl = GeneralizedLinearModel.fit(X,y,'Categorical',[2,3]);
% or equivalently
mdl = LinearModel.fit(X,y,'Categorical',logical([0 1 1 0 0 0]));
```

- For a dataset array `ds`, fitting functions assume that these data types are categorical:
 - Logical
 - Categorical (nominal or ordinal)
 - String or character array

If you want to indicate that a numeric predictor is categorical, use the 'Categorical' name-value pair.

Represent missing numeric data as NaN. To represent missing data for other data types, see “Missing Group Values” on page 2-74.

Dataset Array for Input and Response Data

For example, to create a dataset array from an Excel spreadsheet:

```
ds = dataset('XLSFile','hospital.xls',...
            'ReadObsNames',true);
```

To create a dataset array from workspace variables:

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
```

Numeric Matrix for Input Data, Numeric Vector for Response

For example, to create numeric arrays from workspace variables:

```
load carsmall
X = [Weight Horsepower Cylinders Model_Year];
y = MPG;
```

To create numeric arrays from an Excel spreadsheet:

```
[X Xnames] = xlsread('hospital.xls');  
y = X(:,4); % response y is systolic pressure  
X(:,4) = []; % remove y from the X matrix
```

Notice that the nonnumeric entries, such as `sex`, do not appear in `X`.

Choose a Fitting Method

There are three ways to fit a model to data:

- “Least-Squares Fit” on page 9-10
- “Robust Fit” on page 9-10
- “Stepwise Fit” on page 9-10

Least-Squares Fit

Use `LinearModel.fit` to construct a least-squares fit of a model to the data. This method is best when you are reasonably certain of the model’s form, and mainly need to find its parameters. This method is also useful when you want to explore a few models. The method requires you to examine the data manually to discard outliers, though there are techniques to help (see “Residuals — Model Quality for Training Data” on page 9-21).

Robust Fit

Use `LinearModel.fit` with the `RobustOpts` name-value pair to create a model that is little affected by outliers. Robust fitting saves you the trouble of manually discarding outliers. However, `step` does not work with robust fitting. This means that when you use robust fitting, you cannot search stepwise for a good model.

Stepwise Fit

Use `LinearModel.stepwise` to find a model, and fit parameters to the model. `LinearModel.stepwise` starts from one model, such as a constant, and adds or subtracts terms one at a time, choosing an optimal term each time in a greedy fashion, until it cannot improve further. Use stepwise fitting to find a good model, which is one that has only relevant terms.

The result depends on the starting model. Usually, starting with a constant model leads to a small model. Starting with more terms can lead to a more complex model, but one that has lower mean squared error. See “Compare large and small stepwise models” on page 9-108.

You cannot use robust options along with stepwise fitting. So after a stepwise fit, examine your model for outliers (see “Residuals — Model Quality for Training Data” on page 9-21).

Choose a Model or Range of Models

There are several ways of specifying a model for linear regression. Use whichever you find most convenient.

- “Brief String” on page 9-12
- “Terms Matrix” on page 9-12
- “Formula” on page 9-16

For `LinearModel.fit`, the model specification you give is the model that is fit. If you do not give a model specification, the default is 'linear'.

For `LinearModel.stepwise`, the model specification you give is the starting model, which the stepwise procedure tries to improve. If you do not give a model specification, the default starting model is 'constant', and the default upper bounding model is 'interactions'. Change the upper bounding model using the `Upper` name-value pair.

Note There are other ways of selecting models, such as using `lasso`, `lassoglm`, `sequentialfs`, or `plsregress`.

Brief String

String	Model Type
'constant'	Model contains only a constant (intercept) term.
'linear'	Model contains an intercept and linear terms for each predictor.
'interactions'	Model contains an intercept, linear terms, and all products of pairs of distinct predictors (no squared terms).
'purequadratic'	Model contains an intercept, linear terms, and squared terms.
'quadratic'	Model contains an intercept, linear terms, interactions, and squared terms.
'polyijk'	Model is a polynomial with all terms up to degree i in the first predictor, degree j in the second predictor, etc. Use numerals 0 through 9. For example, 'poly2111' has a constant plus all linear and product terms, and also contains terms with predictor 1 squared.

For example, to specify an interaction model using `LinearModel.fit` with matrix predictors:

```
mdl = LinearModel.fit(X,y,'interactions');
```

To specify a model using `LinearModel.stepwise` and a dataset array `ds` of predictors, suppose you want to start from a constant and have a linear model upper bound. Assume the response variable in `ds` is in the third column.

```
mdl2 = LinearModel.stepwise(ds,'constant',...
    'Upper','linear','ResponseVar',3);
```

Terms Matrix

A terms matrix is a T -by- $P+1$ matrix specifying terms in a model, where T is the number of terms, P is the number of predictor variables, and plus one is for the response variable. The value of $T(i, j)$ is the exponent of variable j in term i . For example, if there are three predictor variables A , B , and C :

```
[0 0 0 0] % constant term or intercept
[0 1 0 0] % B; equivalently, A^0 * B^1 * C^0
[1 0 1 0] % A*C
[2 0 0 0] % A^2
[0 1 2 0] % B*(C^2)
```

The 0 at the end of each term represents the response variable. In general,

- If you have the variables in a dataset array, then a 0 must represent the response variable depending on the position of the response variable in the dataset array. For example:

Load sample data and define the dataset array.

```
load hospital
ds = dataset(hospital.Sex,hospital.BloodPressure(:,1),hospital.Age,...
hospital.Smoker,'VarNames',{'Sex','BloodPressure','Age','Smoker'});
```

Represent the linear model 'BloodPressure ~ 1 + Sex + Age + Smoker' in a terms matrix. The response variable is in the second column of the data set array, so there must be a column of zeros for the response variable in the second column of the term matrix.

```
T = [0 0 0 0;1 0 0 0;0 0 1 0;0 0 0 1]
```

T =

```
    0    0    0    0
    1    0    0    0
    0    0    1    0
    0    0    0    1
```

Redefine the dataset array.

```
ds = dataset(hospital.BloodPressure(:,1),hospital.Sex,hospital.Age,...
hospital.Smoker,'VarNames',{'BloodPressure','Sex','Age','Smoker'});
```

Now, the response variable is the first term in the data set array. Specify the same linear model, 'BloodPressure ~ 1 + Sex + Age + Smoker', using a term matrix.

```
T = [0 0 0 0;0 1 0 0;0 0 1 0;0 0 0 1]
```

```
T =
      0      0      0      0
      0      1      0      0
      0      0      1      0
      0      0      0      1
```

- If you have the predictor and response variables in a matrix and column vector, then you must include a 0 for the response variable at the end of each term. For example:

Load sample data and define the matrix of predictors.

```
load carsmall
X = [Acceleration,Weight];
```

Specify the model 'MPG ~ Acceleration + Weight + Acceleration:Weight + Weight^2' using a term matrix and fit the model to data. This model includes the main effect and two way interaction terms for the variables, Acceleration and Weight, and a second order term for the variable, Weight.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0;0 2 0]
```

```
T =
      0      0      0
      1      0      0
      0      1      0
      1      1      0
      0      2      0
```

Fit a linear model.

```
mdl = LinearModel.fit(X,MPG,T)
```

```
mdl =
```

```
Linear regression model:
y ~ 1 + x1*x2 + x2^2
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	48.906	12.589	3.8847	0.00019665
x1	0.54418	0.57125	0.95261	0.34337
x2	-0.012781	0.0060312	-2.1192	0.036857
x1:x2	-0.00010892	0.00017925	-0.6076	0.545
x2^2	9.7518e-07	7.5389e-07	1.2935	0.19917

Number of observations: 94, Error degrees of freedom: 89

Root Mean Squared Error: 4.1

R-squared: 0.751, Adjusted R-Squared 0.739

F-statistic vs. constant model: 67, p-value = 4.99e-26

Only the intercept and x2 term, which corresponds to the Weight variable, are significant at the 5% significance level.

Now, perform a stepwise regression with a constant model as the starting model and a linear model with interactions as the upper model.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0];
mdl = LinearModel.stepwise(X,MPG,[0 0 0],'upper',T)
```

1. Adding x2, FStat = 259.3087, pValue = 1.643351e-28

```
mdl =
```

Linear regression model:

$$y \sim 1 + x2$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	49.238	1.6411	30.002	2.7015e-49
x2	-0.0086119	0.0005348	-16.103	1.6434e-28

Number of observations: 94, Error degrees of freedom: 92

Root Mean Squared Error: 4.13

R-squared: 0.738, Adjusted R-Squared 0.735

F-statistic vs. constant model: 259, p-value = 1.64e-28

The results of the stepwise regression are consistent with the results of `LinearModel.fit` in the previous step.

Formula

A formula for a model specification is a string of the form

`'Y ~ terms'`,

- *Y* is the response name.
- *terms* contains
 - Variable names
 - + to include the next variable
 - - to exclude the next variable
 - : to define an interaction, a product of terms
 - * to define an interaction and all lower-order terms
 - ^ to raise the predictor to a power, exactly as in * repeated, so ^ includes lower order terms as well
 - () to group terms

Tip Formulas include a constant (intercept) term by default. To exclude a constant term from the model, include -1 in the formula.

Examples:

`'Y ~ A + B + C'` is a three-variable linear model with intercept.

`'Y ~ A + B + C - 1'` is a three-variable linear model without intercept.

`'Y ~ A + B + C + B^2'` is a three-variable model with intercept and a B^2 term.

`'Y ~ A + B^2 + C'` is the same as the previous example, since B^2 includes a B term.

`'Y ~ A + B + C + A:B'` includes an $A*B$ term.

`'Y ~ A*B + C'` is the same as the previous example, since $A*B = A + B + A:B$.

`'Y ~ A*B*C - A:B:C'` has all interactions among A, B, and C, except the three-way interaction.

`'Y ~ A*(B + C + D)'` has all linear terms, plus products of A with each of the other variables.

For example, to specify an interaction model using `LinearModel.fit` with matrix predictors:

```
mdl = LinearModel.fit(X,y,'y ~ x1*x2*x3 - x1:x2:x3');
```

To specify a model using `LinearModel.stepwise` and a dataset array `ds` of predictors, suppose you want to start from a constant and have a linear model upper bound. Assume the response variable in `ds` is named 'y', and the predictor variables are named 'x1', 'x2', and 'x3'.

```
mdl2 = LinearModel.stepwise(ds,'y ~ 1','Upper','y ~ x1 + x2 + x3');
```

Fit Model to Data

The most common optional arguments for fitting:

- For robust regression in `LinearModel.fit`, set the 'RobustOpts' name-value pair to 'on'.
- Specify an appropriate upper bound model in `LinearModel.stepwise`, such as set 'Upper' to 'linear'.
- Indicate which variables are categorical using the 'CategoricalVars' name-value pair. Provide a vector with column numbers, such as [1 6] to specify that predictors 1 and 6 are categorical. Alternatively, give a logical vector the same length as the data columns, with a 1 entry indicating that variable is categorical. If there are seven predictors, and predictors 1 and 6 are categorical, specify `logical([1,0,0,0,0,1,0])`.
- For a dataset array, specify the response variable using the 'ResponseVar' name-value pair. The default is the last column in the array.

For example,

```
mdl = LinearModel.fit(X,y,'linear',...
    'RobustOpts','on','CategoricalVars',3);
mdl2 = LinearModel.stepwise(ds,'constant',...
    'ResponseVar','MPG','Upper','quadratic');
```

Examine Quality and Adjust the Fitted Model

After fitting a model, examine the result.

- “Model Display” on page 9-18

- “ANOVA” on page 9-19
- “Diagnostic Plots” on page 9-20
- “Residuals — Model Quality for Training Data” on page 9-21
- “Plots to Understand Predictor Effects” on page 9-26
- “Plots to Understand Terms Effects” on page 9-31
- “Change Models” on page 9-33

Model Display

A linear regression model shows several diagnostics when you enter its name or enter `disp mdl`. This display gives some of the basic information to check whether the fitted model represents the data adequately.

For example, fit a linear model to data constructed with two out of five predictors not present and with no intercept term:

```
X = randn(100,5);
y = X*[1;0;3;0;-1]+randn(100,1);
mdl = LinearModel.fit(X,y)
```

```
mdl =
```

```
Linear regression model:
```

```
y ~ 1 + x1 + x2 + x3 + x4 + x5
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	0.038164	0.099458	0.38372	0.70205
x1	0.92794	0.087307	10.628	8.5494e-18
x2	-0.075593	0.10044	-0.75264	0.45355
x3	2.8965	0.099879	29	1.1117e-48
x4	0.045311	0.10832	0.41831	0.67667
x5	-0.99708	0.11799	-8.4504	3.593e-13

```
Number of observations: 100, Error degrees of freedom: 94
```

```
Root Mean Squared Error: 0.972
```

```
R-squared: 0.93, Adjusted R-Squared 0.926
```

```
F-statistic vs. constant model: 248, p-value = 1.5e-52
```

Notice that:

- The display contains the estimated values of each coefficient in the Estimate column. These values are reasonably near the true values [0;1;0;2;0;-1].
- There is a standard error column for the coefficient estimates.
- The reported pValue (which are derived from the t statistics under the assumption of normal errors) for predictors 1, 3, and 5 are extremely small. These are the three predictors that were used to create the response data y .
- The pValue for (Intercept), x_2 and x_4 are much larger than 0.01. These three predictors were not used to create the response data y .
- The display contains R^2 , adjusted R^2 , and F statistics.

ANOVA

To examine the quality of the fitted model, consult an ANOVA table. For example, use `anova` on a linear model with five predictors:

```
X = randn(100,5);
y = X*[1;0;3;0;-1]+randn(100,1);
mdl = LinearModel.fit(X,y);
tbl = anova(mdl)
```

```
tbl =
```

	SumSq	DF	MeanSq	F	pValue
x1	106.62	1	106.62	112.96	8.5494e-18
x2	0.53464	1	0.53464	0.56646	0.45355
x3	793.74	1	793.74	840.98	1.1117e-48
x4	0.16515	1	0.16515	0.17498	0.67667
x5	67.398	1	67.398	71.41	3.593e-13
Error	88.719	94	0.94382		

This table gives somewhat different results than the default display (see “Model Display” on page 9-18). The table clearly shows that the effects of x_2 and x_4 are not significant. Depending on your goals, consider removing x_2 and x_4 from the model.

Diagnostic Plots

Diagnostic plots help you identify outliers, and see other problems in your model or fit. For example, load the `carsmall` data, and make a model of MPG as a function of `Cylinders` (nominal) and `Weight`:

```
load carsmall
ds = dataset(Weight,MPG,Cylinders);
ds.Cylinders = ordinal(ds.Cylinders);
mdl = LinearModel.fit(ds,'MPG ~ Cylinders*Weight + Weight^2');
```

Make a leverage plot of the data and model.

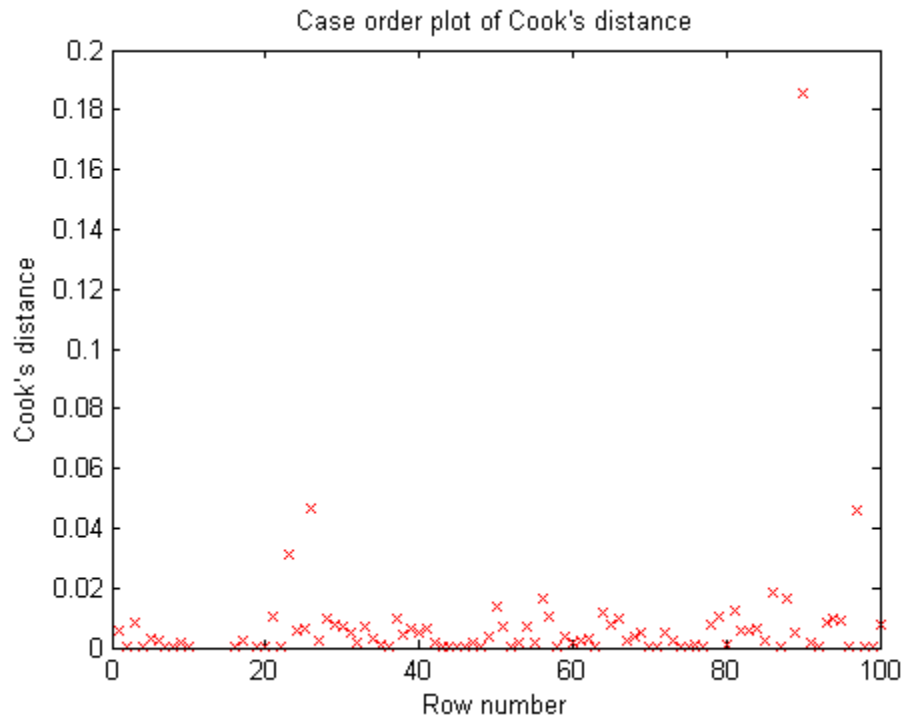
```
plotDiagnostics(mdl)
```



There are a few points with high leverage. But this plot does not reveal whether the high-leverage points are outliers.

Look for points with large Cook's distance.

```
plotDiagnostics(md1, 'cookd')
```



There is one point with large Cook's distance. Identify it and remove it from the model. You can use the Data Cursor to click the outlier and identify it, or identify it programmatically:

```
[~,larg] = max(md1.Diagnostics.CooksDistance);
md12 = LinearModel.fit(ds,'MPG ~ Cylinders*Weight + Weight^2',...
    'Exclude',larg);
```

Residuals – Model Quality for Training Data

There are several residual plots to help you discover errors, outliers, or correlations in the model or data. The simplest residual plots are the default histogram plot, which shows the range of the residuals and their frequencies,

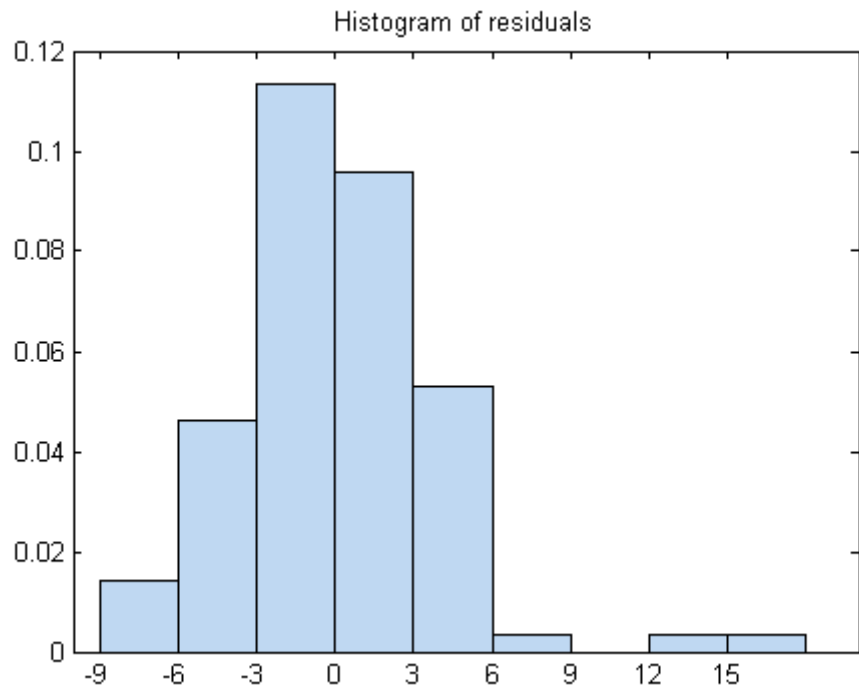
and the probability plot, which shows how the distribution of the residuals compares to a normal distribution with matched variance.

Load the carsmall data, and make a model of MPG as a function of Cylinders (nominal) and Weight:

```
load carsmall
ds = dataset(Weight,MPG,Cylinders);
ds.Cylinders = ordinal(ds.Cylinders);
mdl = LinearModel.fit(ds,'MPG ~ Cylinders*Weight + Weight^2');
```

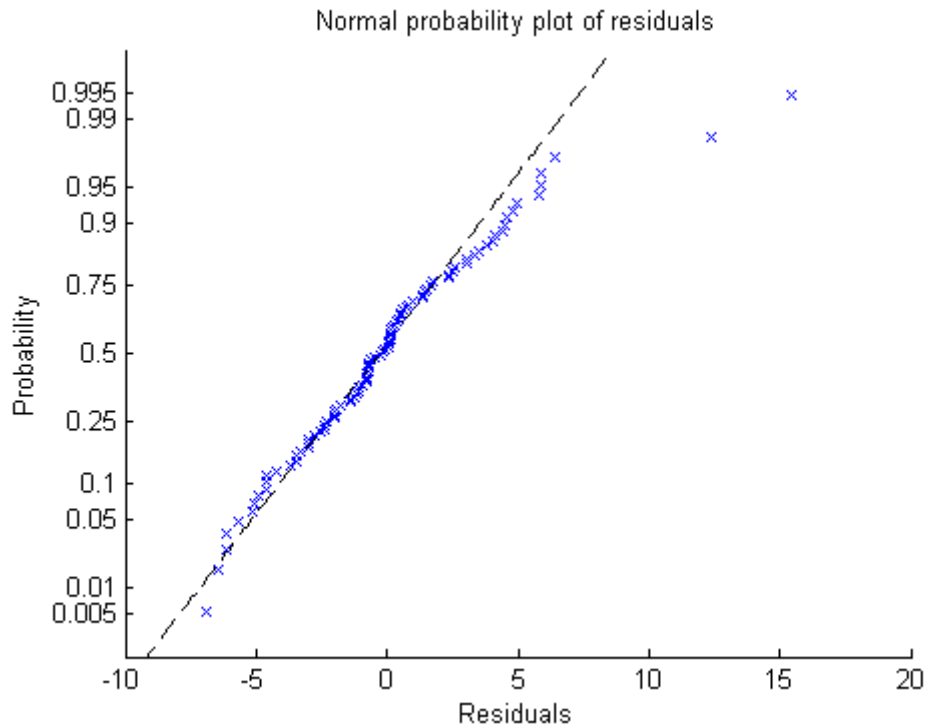
Examine the residuals:

```
plotResiduals(mdl)
```



The observations above 12 are potential outliers.

```
plotResiduals mdl, 'probability')
```



The two potential outliers appear on this plot as well. Otherwise, the probability plot seems reasonably straight, meaning a reasonable fit to normally distributed residuals.

You can identify the two outliers and remove them from the data:

```
out1 = find(mdl.Residuals.Raw > 12)
```

```
out1 =
```

```
90
```

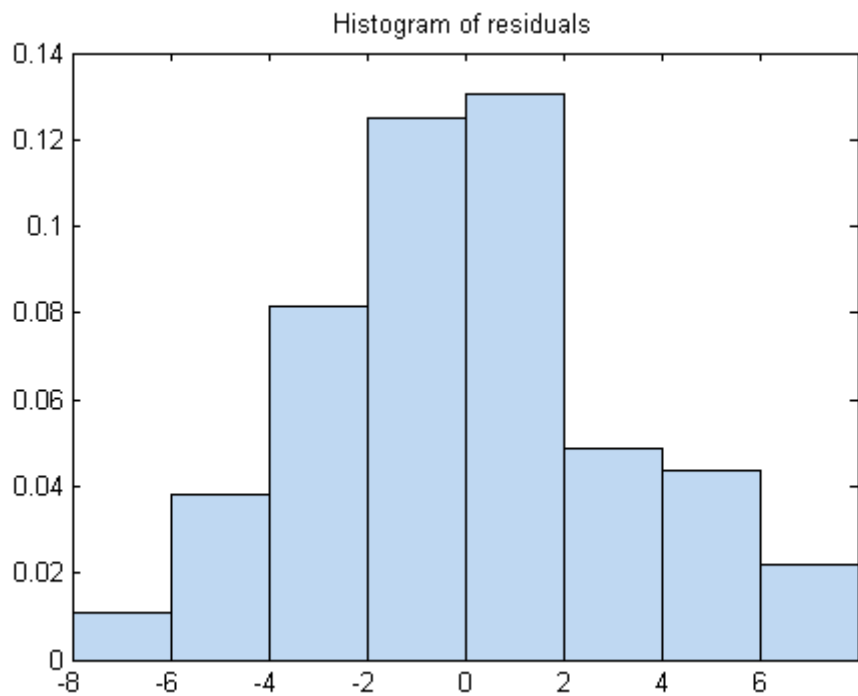
```
97
```

To remove the outliers, use the Exclude name-value pair:

```
md12 = LinearModel.fit(ds, 'MPG ~ Cylinders*Weight + Weight^2', ...  
                        'Exclude', out1);
```

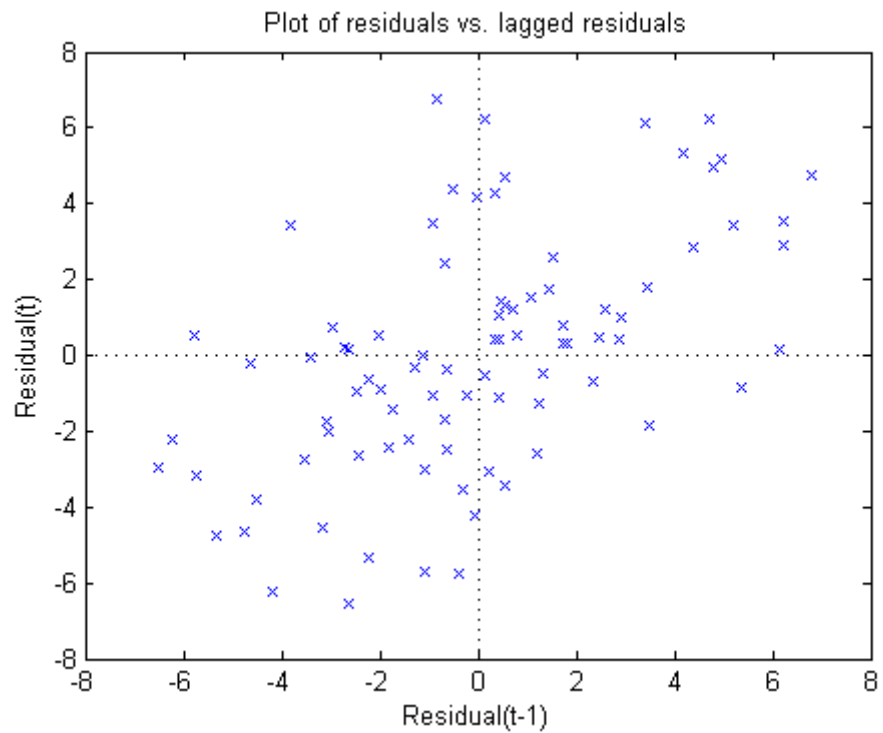
Examine a residuals plot of md12:

```
plotResiduals(md12)
```



The new residuals plot looks fairly symmetric, without obvious problems. However, there might be some serial correlation among the residuals. Create a new plot to see if such an effect exists.

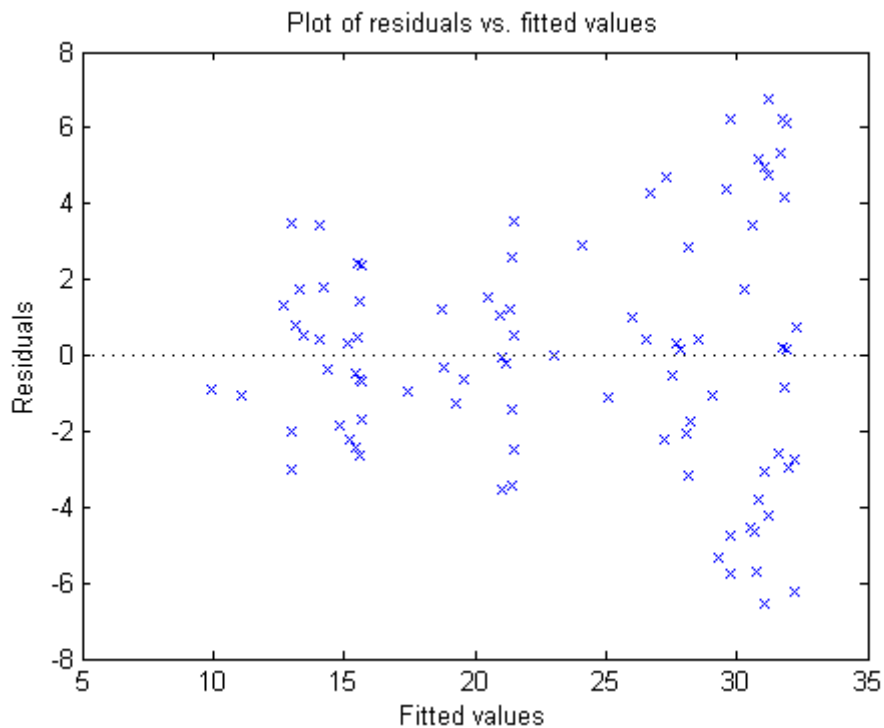
```
plotResiduals(md12, 'lagged')
```

The scatter plot shows many more crosses in the upper-right and lower-left quadrants than in the other two quadrants, indicating positive serial correlation among the residuals.

Another potential issue is when residuals are large for large observations. See if the current model has this issue.

```
plotResiduals(md12, 'fitted')
```



There is some tendency for larger fitted values to have larger residuals. Perhaps the model errors are proportional to the measured values.

Plots to Understand Predictor Effects

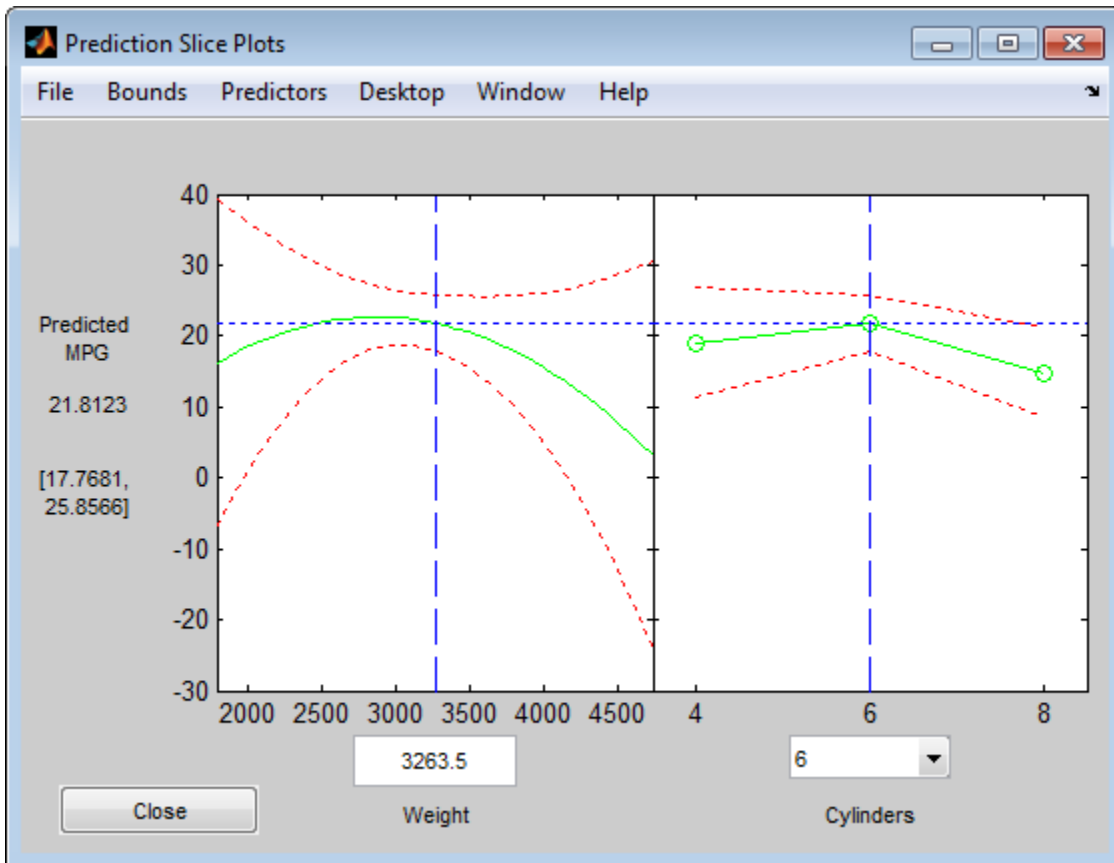
This example shows how to understand the effect each predictor has on a regression model using a variety of available plots.

- 1 Create a model of mileage from some predictors in the carsmall data.

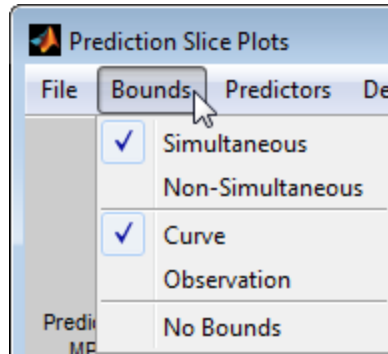
```
load carsmall
ds = dataset(Weight,MPG,Cylinders);
ds.Cylinders = ordinal(ds.Cylinders);
mdl = LinearModel.fit(ds,'MPG ~ Cylinders*Weight + Weight^2');
```

- 2 Examine a slice plot of the responses. This displays the effect of each predictor separately.

```
plotSlice mdl
```

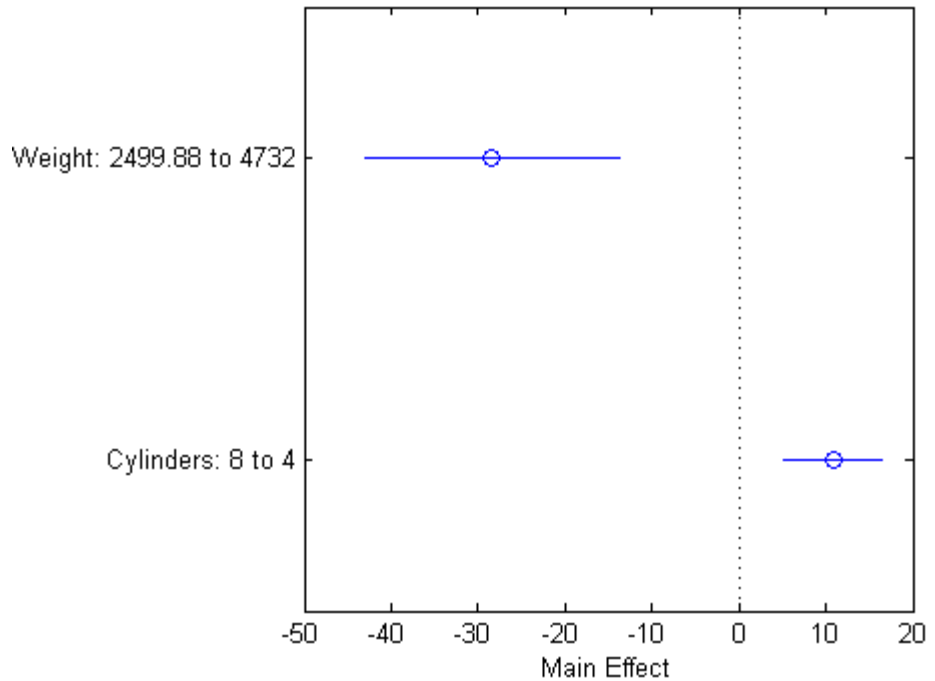


You can drag the individual predictor values, which are represented by dashed blue vertical lines. You can also choose between simultaneous and non-simultaneous confidence bounds, which are represented by dashed red curves.



- 3 Use an effects plot to show another view of the effect of predictors on the response.

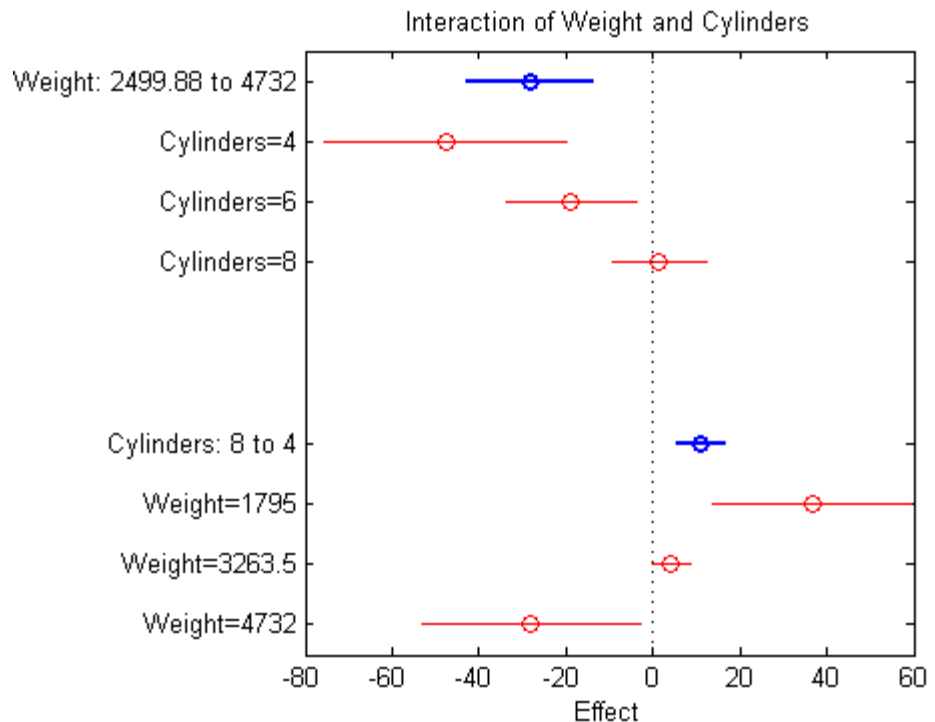
```
plotEffects mdl)
```



This plot shows that changing Weight from about 2500 to 4732 lowers MPG by about 30 (the location of the upper blue circle). It also shows that changing the number of cylinders from 8 to 4 raises MPG by about 10 (the lower blue circle). The horizontal blue lines represent confidence intervals for these predictions. The predictions come from averaging over one predictor as the other is changed. In cases such as this, where the two predictors are correlated, be careful when interpreting the results.

- 4 Instead of viewing the effect of averaging over a predictor as the other is changed, examine the joint interaction in an interaction plot.

```
plotInteraction(md1, 'Weight', 'Cylinders')
```

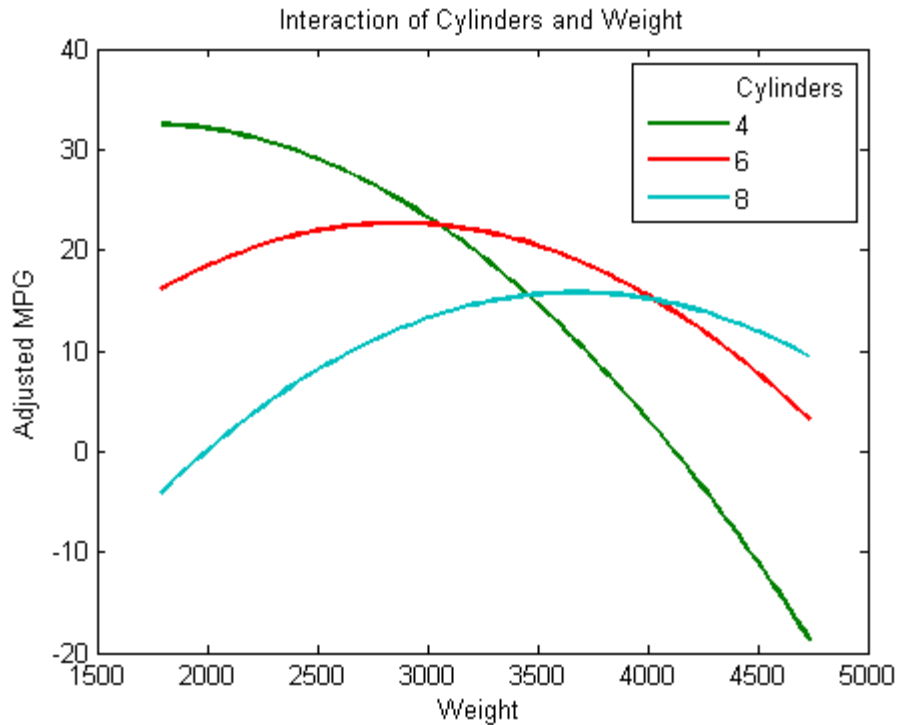


The interaction plot shows the effect of changing one predictor with the other held fixed. In this case, the plot is much more informative. It shows, for example, that lowering the number of cylinders in a relatively light car

(Weight = 1795) leads to an increase in mileage, but lowering the number of cylinders in a relatively heavy car (Weight = 4732) leads to a decrease in mileage.

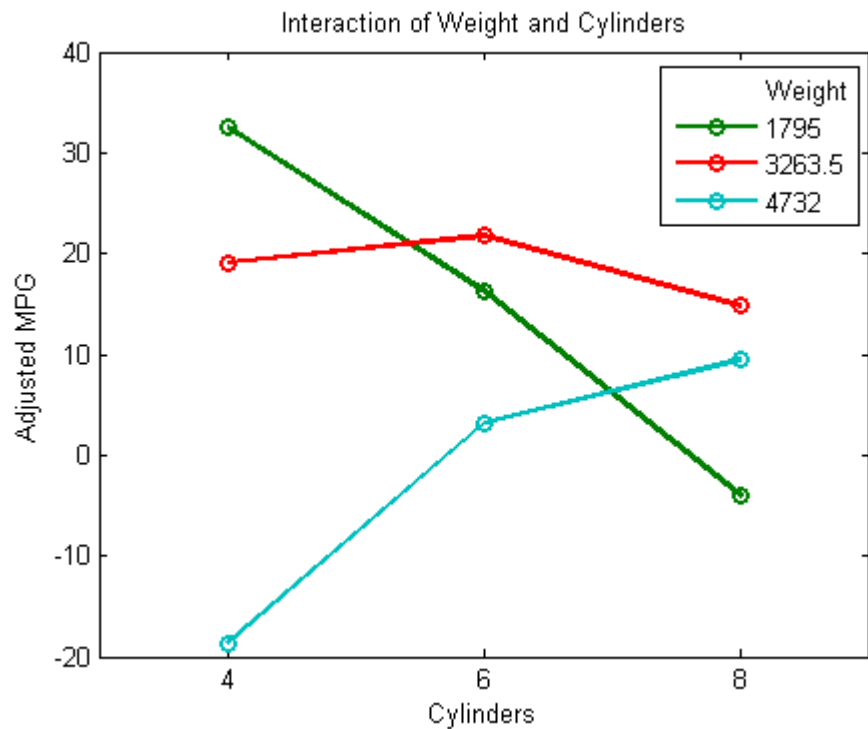
- For an even more detailed look at the interactions, look at an interaction plot with predictions. This plot holds one predictor fixed while varying the other, and plots the effect as a curve. Look at the interactions for various fixed numbers of cylinders.

```
plotInteraction(md1, 'Cylinders', 'Weight', 'predictions')
```



Now look at the interactions with various fixed levels of weight.

```
plotInteraction(md1, 'Weight', 'Cylinders', 'predictions')
```



Plots to Understand Terms Effects

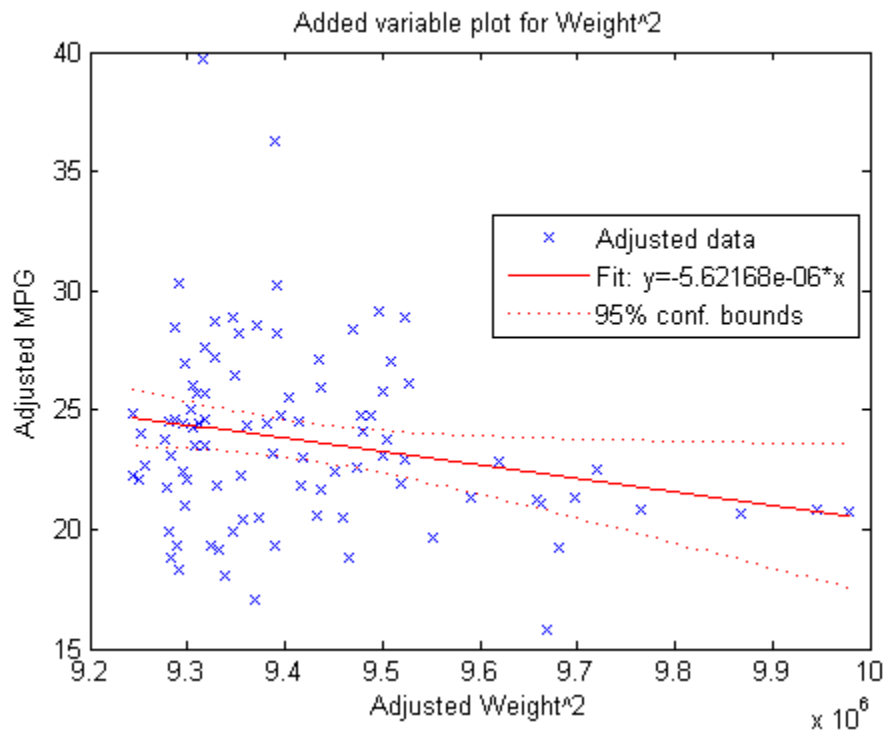
This example shows how to understand the effect of each term in a regression model using a variety of available plots.

- 1 Create a model of mileage from some predictors in the carsmall data.

```
load carsmall
ds = dataset(Weight,MPG,Cylinders);
ds.Cylinders = ordinal(ds.Cylinders);
mdl = LinearModel.fit(ds,'MPG ~ Cylinders*Weight + Weight^2');
```

- 2 Create an added variable plot with Weight^2 as the added variable.

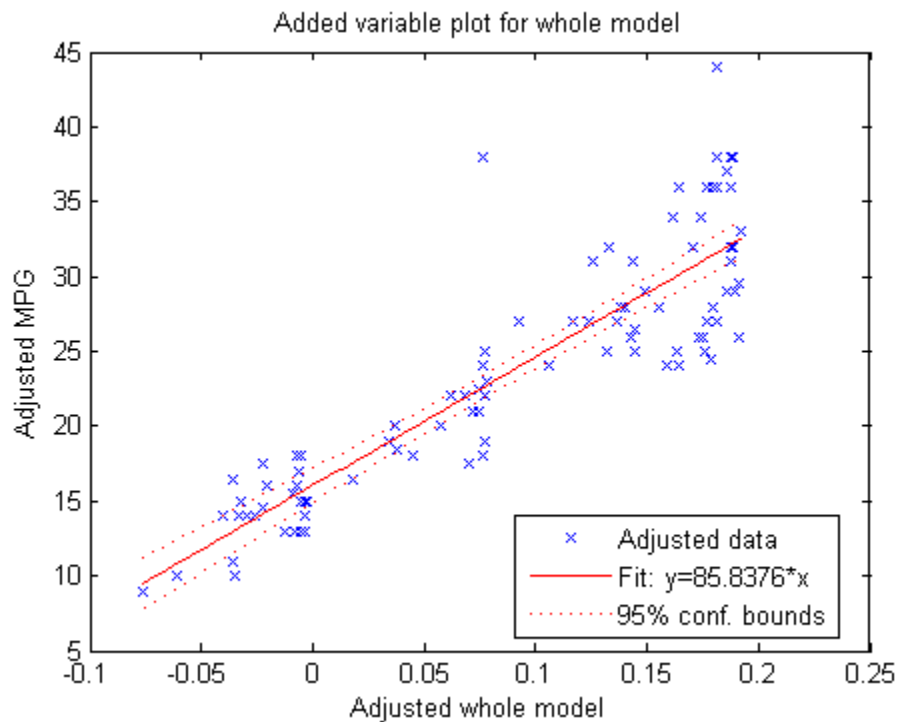
```
plotAdded(mdl, 'Weight^2')
```



This plot shows the results of fitting both Weight^2 and MPG to the terms other than Weight^2 . The reason to use `plotAdded` is to understand what additional improvement in the model you get by adding Weight^2 . The coefficient of a line fit to these points is the coefficient of Weight^2 in the full model. The Weight^2 predictor is just over the edge of significance ($p\text{Value} < 0.05$) as you can see in the coefficients table display. You can see that in the plot as well. The confidence bounds look like they could not contain a horizontal line (constant y), so a zero-slope model is not consistent with the data.

- 3** Create an added variable plot for the model as a whole.

```
plotAdded(md1)
```

The model as a whole is very significant, so the bounds don't come close to containing a horizontal line. The slope of the line is the slope of a fit to the predictors projected onto their best-fitting direction, or in other words, the norm of the coefficient vector.

Change Models

There are two ways to change a model:

- `step` — Add or subtract terms one at a time, where `step` chooses the most important term to add or remove.
- `addTerms` and `removeTerms` — Add or remove specified terms. Give the terms in any of the forms described in “Choose a Model or Range of Models” on page 9-11.

If you created a model using `LinearModel.stepwise`, `step` can have an effect only if you give different upper or lower models. `step` does not work when you fit a model using `RobustOpts`.

For example, start with a linear model of mileage from the `carbig` data:

```
load carbig
ds = dataset(Acceleration,Displacement,Horsepower,Weight,MPG);
mdl = LinearModel.fit(ds,'linear','ResponseVar','MPG')
```

```
mdl =
```

Linear regression model:

```
MPG ~ 1 + Acceleration + Displacement + Horsepower + Weight
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	45.251	2.456	18.424	7.0721e-55
Acceleration	-0.023148	0.1256	-0.1843	0.85388
Displacement	-0.0060009	0.0067093	-0.89441	0.37166
Horsepower	-0.043608	0.016573	-2.6312	0.008849
Weight	-0.0052805	0.00081085	-6.5123	2.3025e-10

Number of observations: 392, Error degrees of freedom: 387

Root Mean Squared Error: 4.25

R-squared: 0.707, Adjusted R-Squared 0.704

F-statistic vs. constant model: 233, p-value = 9.63e-102

Try to improve the model using `step` for up to 10 steps:

```
mdl1 = step(mdl,'NSteps',10)
```

```
1. Adding Displacement:Horsepower, FStat = 87.4802, pValue = 7.05273e-19
```

```
mdl1 =
```

Linear regression model:

```
MPG ~ 1 + Acceleration + Weight + Displacement*Horsepower
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	61.285	2.8052	21.847	1.8593e-69
Acceleration	-0.34401	0.11862	-2.9	0.0039445
Displacement	-0.081198	0.010071	-8.0623	9.5014e-15
Horsepower	-0.24313	0.026068	-9.3265	8.6556e-19
Weight	-0.0014367	0.00084041	-1.7095	0.088166
Displacement:Horsepower	0.00054236	5.7987e-05	9.3531	7.0527e-19

Number of observations: 392, Error degrees of freedom: 386

Root Mean Squared Error: 3.84

R-squared: 0.761, Adjusted R-Squared 0.758

F-statistic vs. constant model: 246, p-value = 1.32e-117

step stopped after just one change.

To try to simplify the model, remove the Acceleration and Weight terms from mdl1:

```
mdl2 = removeTerms(mdl1, 'Acceleration + Weight')
```

```
mdl2 =
```

Linear regression model:

```
MPG ~ 1 + Displacement*Horsepower
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	53.051	1.526	34.765	3.0201e-121
Displacement	-0.098046	0.0066817	-14.674	4.3203e-39
Horsepower	-0.23434	0.019593	-11.96	2.8024e-28
Displacement:Horsepower	0.00058278	5.193e-05	11.222	1.6816e-25

Number of observations: 392, Error degrees of freedom: 388

Root Mean Squared Error: 3.94

R-squared: 0.747, Adjusted R-Squared 0.745

F-statistic vs. constant model: 381, p-value = 3e-115

mdl2 uses just Displacement and Horsepower, and has nearly as good a fit to the data as mdl1 in the Adjusted R-Squared metric.

Predict or Simulate Responses to New Data

There are three ways to use a linear model to predict or simulate the response to new data:

- “predict” on page 9-36
- “feval” on page 9-37
- “random” on page 9-38

predict

This example shows how to predict and obtain confidence intervals on the predictions using the predict method.

- 1 Load the carbig data and make a default linear model of the response MPG to the Acceleration, Displacement, Horsepower, and Weight predictors.

```
load carbig
X = [Acceleration,Displacement,Horsepower,Weight];
mdl = LinearModel.fit(X,MPG);
```

- 2 Create a three-row array of predictors from the minimal, mean, and maximal values. There are some NaN values, so use functions that ignore NaN values.

```
Xnew = [nanmin(X);nanmean(X);nanmax(X)]; % new data
```

- 3 Find the predicted model responses and confidence intervals on the predictions.

```
[NewMPG NewMPGCI] = predict(mdl,Xnew)
```

```
NewMPG =
    34.1345
    23.4078
     4.7751
```

```
NewMPGCI =
    31.6115    36.6575
    22.9859    23.8298
     0.6134     8.9367
```

The confidence bound on the mean response is narrower than those for the minimum or maximum responses, which is quite sensible.

feval

When you construct a model from a dataset array, `feval` is often more convenient for predicting mean responses than `predict`. However, `feval` does not provide confidence bounds.

This example shows how to predict mean responses using the `feval` method.

- 1 Load the `carbig` data and make a default linear model of the response MPG to the Acceleration, Displacement, Horsepower, and Weight predictors.

```
load carbig
ds = dataset(Acceleration,Displacement,Horsepower,Weight,MPG);
mdl = LinearModel.fit(ds,'linear','ResponseVar','MPG');
```

- 2 Create a three-row array of predictors from the minimal, mean, and maximal values. There are some NaN values, so use functions that ignore NaN values.

```
X = [Acceleration,Displacement,Horsepower,Weight];
Xnew = [nanmin(X);nanmean(X);nanmax(X)]; % new data
```

The `Xnew` array is not a dataset array. It has the right number of columns for prediction, so `feval` can use it for predictions.

- 3 Find the predicted model responses.

```
NewMPG = feval(mdl,Xnew)
```

```
NewMPG =
    34.1345
    23.4078
     4.7751
```

random

The `random` method simulates new random response values, equal to the mean prediction plus a random disturbance with the same variance as the training data.

This example shows how to simulate responses using the `random` method.

- 1 Load the `carbig` data and make a default linear model of the response MPG to the Acceleration, Displacement, Horsepower, and Weight predictors.

```
load carbig
X = [Acceleration,Displacement,Horsepower,Weight];
mdl = LinearModel.fit(X,MPG);
```

- 2 Create a three-row array of predictors from the minimal, mean, and maximal values. There are some NaN values, so use functions that ignore NaN values.

```
Xnew = [nanmin(X);nanmean(X);nanmax(X)]; % new data
```

- 3 Generate new predicted model responses including some randomness.

```
rng('default') % for reproducibility
NewMPG = random(mdl,Xnew)
```

```
NewMPG =

    36.4178
    31.1958
    -4.8176
```

- 4 Because a negative value of MPG does not seem sensible, try predicting two more times.

```
NewMPG = random(mdl,Xnew)
```

```
NewMPG =

    37.7959
    24.7615
    -0.7783
```

```
NewMPG = random(md1,Xnew)
```

```
NewMPG =
```

```
32.2931
24.8628
19.9715
```

Clearly, the predictions for the third (maximal) row of `Xnew` are not reliable.

Share Fitted Models

Suppose you have a linear regression model, such as `mdl` from the following commands:

```
load carbig
ds = dataset(Acceleration,Displacement,Horsepower,Weight,MPG);
mdl = LinearModel.fit(ds,'linear','ResponseVar','MPG');
```

To share the model with other people, you can:

- Provide the model display.

```
mdl
```

```
mdl =
```

```
Linear regression model:
```

```
MPG ~ 1 + Acceleration + Displacement + Horsepower + Weight
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	45.251	2.456	18.424	7.0721e-55
Acceleration	-0.023148	0.1256	-0.1843	0.85388
Displacement	-0.0060009	0.0067093	-0.89441	0.37166
Horsepower	-0.043608	0.016573	-2.6312	0.008849
Weight	-0.0052805	0.00081085	-6.5123	2.3025e-10

```
Number of observations: 392, Error degrees of freedom: 387
```

```
Root Mean Squared Error: 4.25
```

```
R-squared: 0.707, Adjusted R-Squared 0.704
F-statistic vs. constant model: 233, p-value = 9.63e-102
```

- Provide just the model definition and coefficients.

```
mdl.CoefficientNames
```

```
ans =
```

```
      '(Intercept)'      'Acceleration'      'Displacement'      'Horsepower'
```

```
mdl.Coefficients.Estimate
```

```
ans =
```

```
45.2511
-0.0231
-0.0060
-0.0436
-0.0053
```

```
mdl.Formula
```

```
ans =
```

```
MPG ~ 1 + Acceleration + Displacement + Horsepower + Weight
```

Linear Regression Workflow

This example shows a typical workflow: import data, fit a regression, test its quality, modify it to improve the quality, and share it.

Step 1. Import the data into a dataset array.

hospital.xls is an Excel spreadsheet containing patient names, sex, age, weight, blood pressure, and dates of treatment in an experimental protocol. First read the data into a dataset array.

```
patients = dataset('XLSFile', 'hospital.xls', ...
                  'ReadObsNames', true);
```

Examine the first row of data.


```
patients(1,:)
```

```
ans =
```

	name	sex	age	wgt	smoke	
YPL-320	'SMITH'	'm'	38	176	1	
	sys	dia	trial1	trial2	trial3	trial4
YPL-320	124	93	18	-99	-99	-99

The `sex` and `smoke` fields seem to have two choices each. So change these fields to nominal.

```
patients.smoke = nominal(patients.smoke,{'No','Yes'});
patients.sex = nominal(patients.sex);
```

Step 2. Create a fitted model.

Your goal is to model the systolic pressure as a function of a patient's age, weight, sex, and smoking status. Create a linear formula for `'sys'` as a function of `'age'`, `'wgt'`, `'sex'`, and `'smoke'`.

```
modelspec = 'sys ~ age + wgt + sex + smoke';
mdl = LinearModel.fit(patients,modelspec)
```

```
mdl =
```

```
Linear regression model:
```

```
sys ~ 1 + sex + age + wgt + smoke
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	118.28	7.6291	15.504	9.1557e-28
sex_m	0.88162	2.9473	0.29913	0.76549
age	0.08602	0.06731	1.278	0.20438
wgt	-0.016685	0.055714	-0.29947	0.76524
smoke_Yes	9.884	1.0406	9.498	1.9546e-15

```
Number of observations: 100, Error degrees of freedom: 95
Root Mean Squared Error: 4.81
```

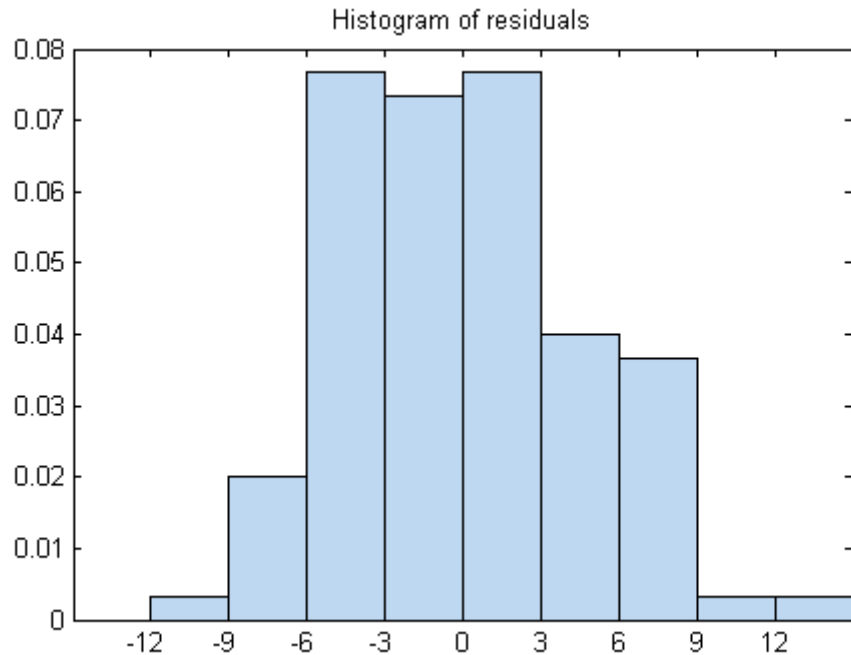
R-squared: 0.508, Adjusted R-Squared 0.487
F-statistic vs. constant model: 24.5, p-value = 5.99e-14

The sex, age, and weight predictors have rather high p -values, indicating that some of these predictors might be unnecessary.

Step 3. Locate and remove outliers.

See if there are outliers in the data that should be excluded from the fit. Plot the residuals.

```
plotResiduals(md1)
```



There is one possible outlier, with a value greater than 12. This is probably not truly an outlier. For demonstration, here is how to find and remove it.

Find the outlier.

```
outlier = mdl.Residuals.Raw > 12;
find(outlier)
```

```
ans =
     84
```

Remove the outlier.

```
mdl = LinearModel.fit(patients,modelspec,...
    'Exclude',84);
```

```
mdl.ObservationInfo(84,:)
```

```
ans =
           Weights  Excluded  Missing  Subset
WXM-486           1        true    false    false
```

Observation 84 is no longer in the model.

Step 4. Simplify the model.

Try to obtain a simpler model, one with fewer predictors but the same predictive accuracy. `step` looks for a better model by adding or removing one term at a time. Allow `step` take up to 10 steps.

```
mdl1 = step(mdl,'NSteps',10)
```

1. Removing wgt, FStat = 4.6001e-05, pValue = 0.9946
2. Removing sex, FStat = 0.063241, pValue = 0.80199

```
mdl1 =
```

```
Linear regression model:
  sys ~ 1 + age + smoke
```

Estimated Coefficients:

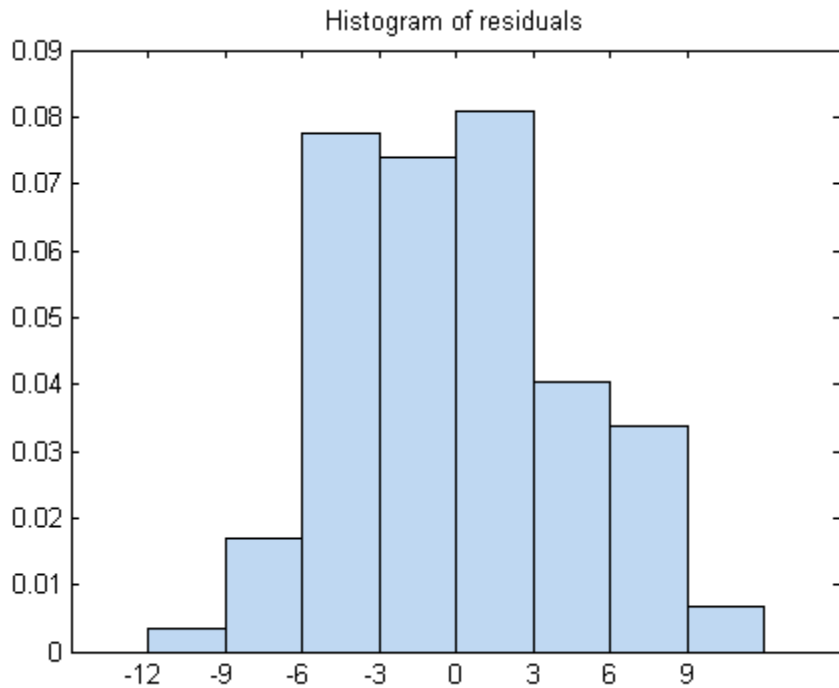
	Estimate	SE	tStat	pValue
(Intercept)	115.11	2.5364	45.383	1.1407e-66
age	0.10782	0.064844	1.6628	0.09962
smoke_Yes	10.054	0.97696	10.291	3.5276e-17

Number of observations: 99, Error degrees of freedom: 96
Root Mean Squared Error: 4.61
R-squared: 0.536, Adjusted R-Squared 0.526
F-statistic vs. constant model: 55.4, p-value = 1.02e-16

step took two steps. This means it could not improve the model further by adding or subtracting a single term.

Plot the effectiveness of the simpler model on the training data.

```
plotResiduals(md11)
```



The residuals look about as small as those of the original model.

Step 5. Predict responses to new data.

Suppose you have four new people, aged 25, 30, 40, and 65, and the first and third smoke. Predict their systolic pressure using `mdl1`.

```
ages = [25;30;40;65];
smoker = {'Yes';'No';'Yes';'No'};
systolicnew = feval(mdl1,ages,smoker)
```

```
systolicnew =
```

```
127.8561
118.3412
129.4734
122.1149
```

To make predictions, you need only the variables that `mdl1` uses.

Step 6. Share the model.

You might want others to be able to use your model for prediction. Access the terms in the linear model.

```
coefnames = mdl1.CoefficientNames
```

```
coefnames =
```

```
 '(Intercept)'      'age'      'smoke_Yes'
```

View the model formula.

```
mdl1.Formula
```

```
ans =
```

```
sys ~ 1 + age + smoke
```

Access the coefficients of the terms.

```
coefvals = mdl1.Coefficients(:,1); % dataset array
coefvals = double(coefvals)
```

```
coefvals =
```

```
115.1066
```

```
0.1078
```

```
10.0540
```

The model is $\text{sys} = 115.1066 + 0.1078 \cdot \text{age} + 10.0540 \cdot \text{smoke}$, where smoke is 1 for a smoker, and 0 otherwise.

Regression Using Dataset Arrays

This example shows how to perform linear and stepwise regression analyses using dataset arrays.

Load sample data.

```
load imports-85
```

Store predictor and response variables in dataset array.

```
ds = dataset(X(:,7),X(:,8),X(:,9),X(:,15),'Varnames',...
{'curb_weight','engine_size','bore','price'});
```

Fit linear regression model.

Fit a linear regression model that explains the price of a car in terms of its curb weight, engine size, and bore.

```
LinearModel.fit(ds,'price-curb_weight+engine_size+bore')
```

```
ans =
```

```
Linear regression model:
price ~ 1 + curb_weight + engine_size + bore
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	64.095	3.703	17.309	2.0481e-41
curb_weight	-0.0086681	0.0011025	-7.8623	2.42e-13
engine_size	-0.015806	0.013255	-1.1925	0.23452
bore	-2.6998	1.3489	-2.0015	0.046711

```
Number of observations: 201, Error degrees of freedom: 197
```

```
Root Mean Squared Error: 3.95
```

```
R-squared: 0.674, Adjusted R-Squared 0.669
```

```
F-statistic vs. constant model: 136, p-value = 1.14e-47
```

The following command also returns the same result because `LinearModel.fit`, by default, assumes the predictor variable is in the last column of the dataset array `ds`.

```
LinearModel.fit(ds)
```

Recreate dataset array and repeat analysis.

This time, put the response variable in the first column of the dataset array.

```
ds = dataset(X(:,15),X(:,7),X(:,8),X(:,9), 'Varnames', ...
{'price', 'curb_weight', 'engine_size', 'bore'});
```

When the response variable is in the first column of `ds`, define its location. For example, `LinearModel.fit`, by default, assumes that `bore` is the response variable. You can define the response variable in the model using either:

```
LinearModel.fit(ds, 'ResponseVar', 'price');
```

or

```
LinearModel.fit(ds, 'ResponseVar', logical([1 0 0 0]));
```

Perform stepwise regression.

```
LinearModel.stepwise(ds, 'quadratic', 'lower', 'price~1', ...
'ResponseVar', 'price')
```

1. Removing `bore^2`, `FStat` = 0.01282, `pValue` = 0.90997
2. Removing `engine_size^2`, `FStat` = 0.078043, `pValue` = 0.78027
3. Removing `curb_weight:bore`, `FStat` = 0.70558, `pValue` = 0.40195

```
ans =
```

```
Linear regression model:
```

```
price ~ 1 + curb_weight*engine_size + engine_size*bore + curb_weight^2
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pVal
(Intercept)	131.13	14.273	9.1873	6.23
curb_weight	-0.043315	0.0085114	-5.0891	8.46

engine_size	-0.17102	0.13844	-1.2354	0
bore	-12.244	4.999	-2.4493	0
curb_weight:engine_size	-6.3411e-05	2.6577e-05	-2.386	0.
engine_size:bore	0.092554	0.037263	2.4838	0.
curb_weight^2	8.0836e-06	1.9983e-06	4.0451	7.54

Number of observations: 201, Error degrees of freedom: 194

Root Mean Squared Error: 3.59

R-squared: 0.735, Adjusted R-Squared 0.726

F-statistic vs. constant model: 89.5, p-value = 3.58e-53

The initial model is a quadratic formula, and the lowest model considered is the constant. Here, `LinearModel.stepwise` performs a backward elimination technique to determine the terms in the model. The final model is $\text{price} \sim 1 + \text{curb_weight} * \text{engine_size} + \text{engine_size} * \text{bore} + \text{curb_weight}^2$, which corresponds to

$$P = \beta_0 + \beta_C C + \beta_E E + \beta_B B + \beta_{CE} CE + \beta_{EB} EB + \beta_{C^2} C^2 + \varepsilon$$

where P is price, C is curb weight, E is engine size, B is bore, β_i is the coefficient for the corresponding term in the model, and ε is the error term. The final model includes all three main effects, the interaction effects for curb weight and engine size and engine size and bore, and the second-order term for curb weight.

See Also

`LinearModel` | `LinearModel.fit` | `LinearModel.stepwise` |

Related Examples

- “Examine Quality and Adjust the Fitted Model” on page 9-17
- “Interpret Linear Regression Results” on page 9-60

Concepts

- “Linear Regression Output and Diagnostic Statistics” on page 9-68

Linear Regression with Interaction Effects

This example shows how to construct and analyze a linear regression model with interaction effects and interpret the results.

Load sample data.

```
load hospital
```

To retain only the first column of blood pressure, store data in a new dataset array.

```
ds = dataset(hospital.Sex,hospital.Age,hospital.Weight,hospital.Smoker,...
hospital.BloodPressure(:,1),'Varnames',{'Sex','Age','Weight','Smoker',...
'BloodPressure'});
```

Perform stepwise linear regression.

For the initial model, use the full model with all terms and their pairwise interactions.

```
mdl = LinearModel.stepwise(ds,'interactions')
```

1. Removing Sex:Smoker, FStat = 0.050738, pValue = 0.8223
2. Removing Weight:Smoker, FStat = 0.07758, pValue = 0.78124
3. Removing Age:Weight, FStat = 1.9717, pValue = 0.16367
4. Removing Sex:Age, FStat = 0.32389, pValue = 0.57067
5. Removing Age:Smoker, FStat = 2.4939, pValue = 0.11768

```
mdl =
```

Linear regression model:

```
BloodPressure ~ 1 + Age + Smoker + Sex*Weight
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	133.17	10.337	12.883	1.76e-22
Sex_Male	-35.269	17.524	-2.0126	0.047015
Age	0.11584	0.067664	1.712	0.090198
Weight	-0.1393	0.080211	-1.7367	0.085722

Smoker_1	9.8307	1.0229	9.6102	1.2391e-15
Sex_Male:Weight	0.2341	0.11192	2.0917	0.039162

Number of observations: 100, Error degrees of freedom: 94
 Root Mean Squared Error: 4.72
 R-squared: 0.53, Adjusted R-Squared 0.505
 F-statistic vs. constant model: 21.2, p-value = 4e-14

The final model in formula form is **BloodPressure ~ 1 + Age + Smoker + Sex*Weight**. This model includes all four main effects (Age, Smoker, Sex, Weight) and the two-way interaction between Sex and Weight. This model corresponds to

$$BP = \beta_0 + \beta_A X_A + \beta_{Sm} I_{Sm} + \beta_S I_S + \beta_W X_W + \beta_{SW} X_W I_S + \varepsilon,$$

where

- BP is the blood pressure
- β_i s are the coefficients
- I_{Sm} is the indicator variable for smoking; $I_{Sm} = 1$ indicates a smoking patient whereas $I_{Sm} = 0$ indicates a nonsmoking patient
- I_S is the indicator variable for sex; $I_S = 1$ indicates a male patient whereas $I_S = 0$ indicates a female patient
- X_A is the Age variable
- X_W is the Weight variable
- ε is the error term

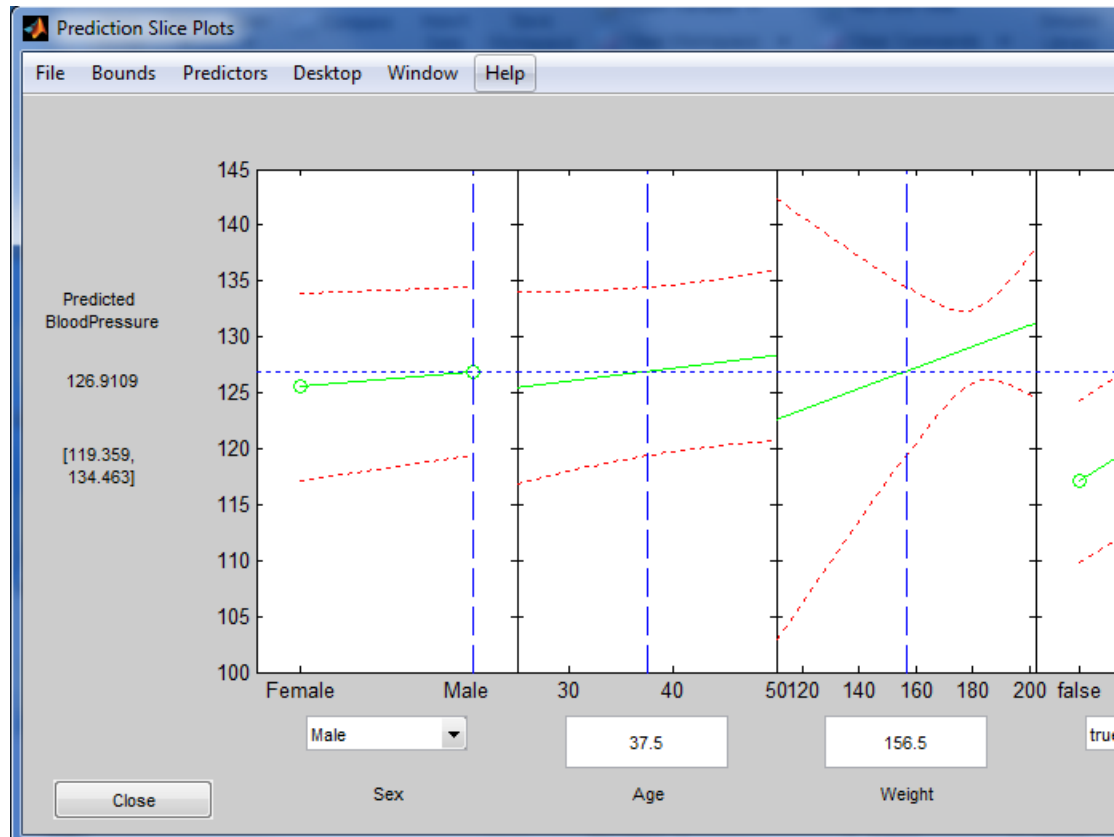
The following table shows the fitted linear model for each gender and smoking combination.

I_{Sm}	I_S	Linear Model
1 (Male)	1 (Smoker)	$BP = (\beta_0 + \beta_{Sm} + \beta_S) + \beta_A X_A + (\beta_W + \beta_{SW}) X_W$ $\hat{BP} = 107.5617 + 0.11584 X_A + 0.11826 X_W$
1 (Male)	0 (Nonsmoker)	$BP = (\beta_0 + \beta_{Sm}) + \beta_A X_A + \beta_W X_W$
0 (Female)	1 (Smoker)	$BP = (\beta_0 + \beta_S) + \beta_A X_A + (\beta_W + \beta_{SW}) X_W$ $\hat{BP} = 97.901 + 0.11584 X_A + 0.11826 X_W$
0 (Female)	0 (Nonsmoker)	$BP = \beta_0 + \beta_A X_A + \beta_W X_W$ $\hat{BP} = 133.17 + 0.11584 X_A - 0.1393 X_W$

As seen from these models, β_{Sm} and β_S show how much the intercept of the response function changes when the indicator variable takes the value 1 compared to when it takes the value 0. β_{SW} , however, shows the effect of the Weight variable on the response variable when the indicator variable for sex takes the value 1 compared to when it takes the value 0. You can explore the main and interaction effects in the final model using the methods of the `LinearModel` class as follows.

Plot prediction slice plots.

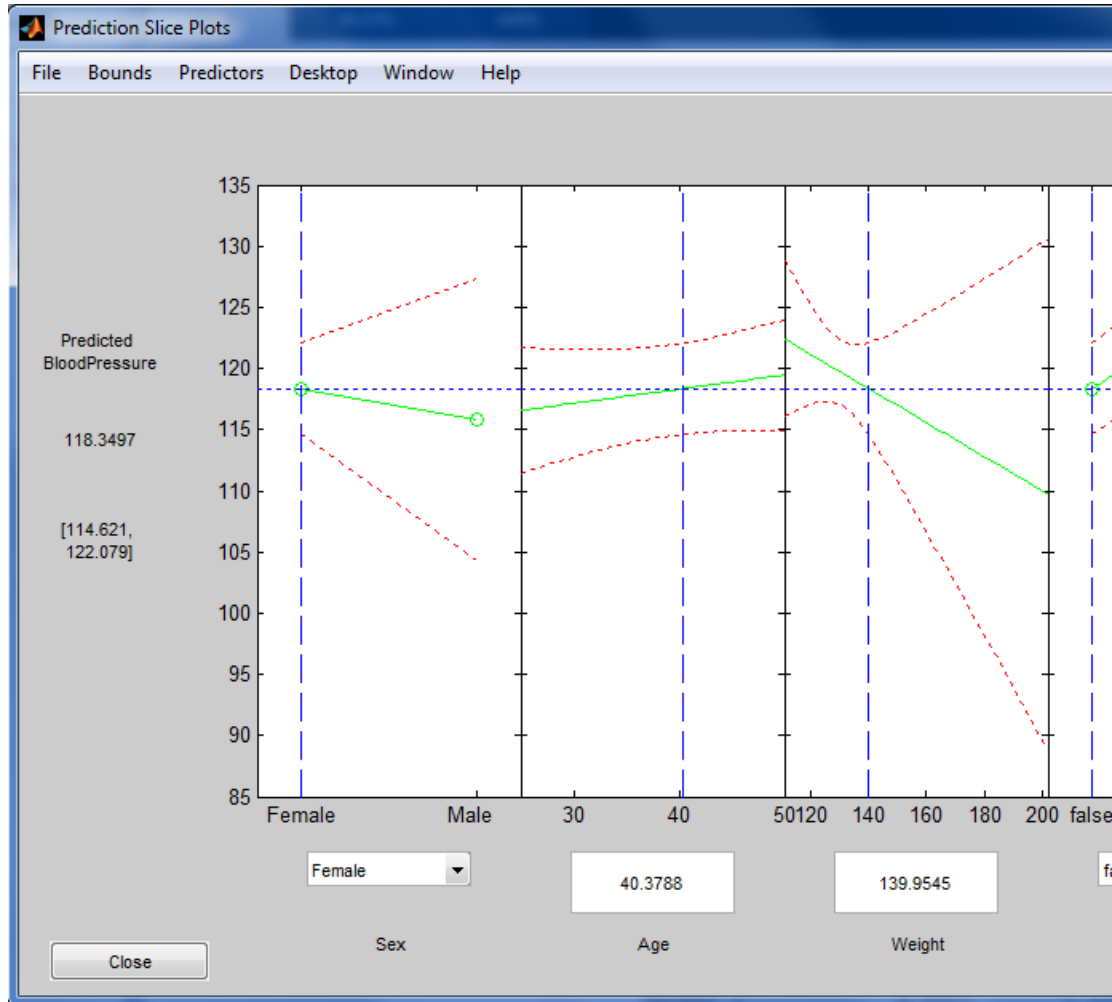
```
figure()
plotSlice mdl
```



This plot shows the main effects for all predictor variables. The green line in each panel shows the change in the response variable as a function of the predictor variable when all other predictor variables are held constant. For example, for a smoking male patient aged 37.5, the expected blood pressure increases as the weight of the patient increases, given all else the same.

The dashed red curves in each panel show the 95% confidence bounds for the predicted response values.

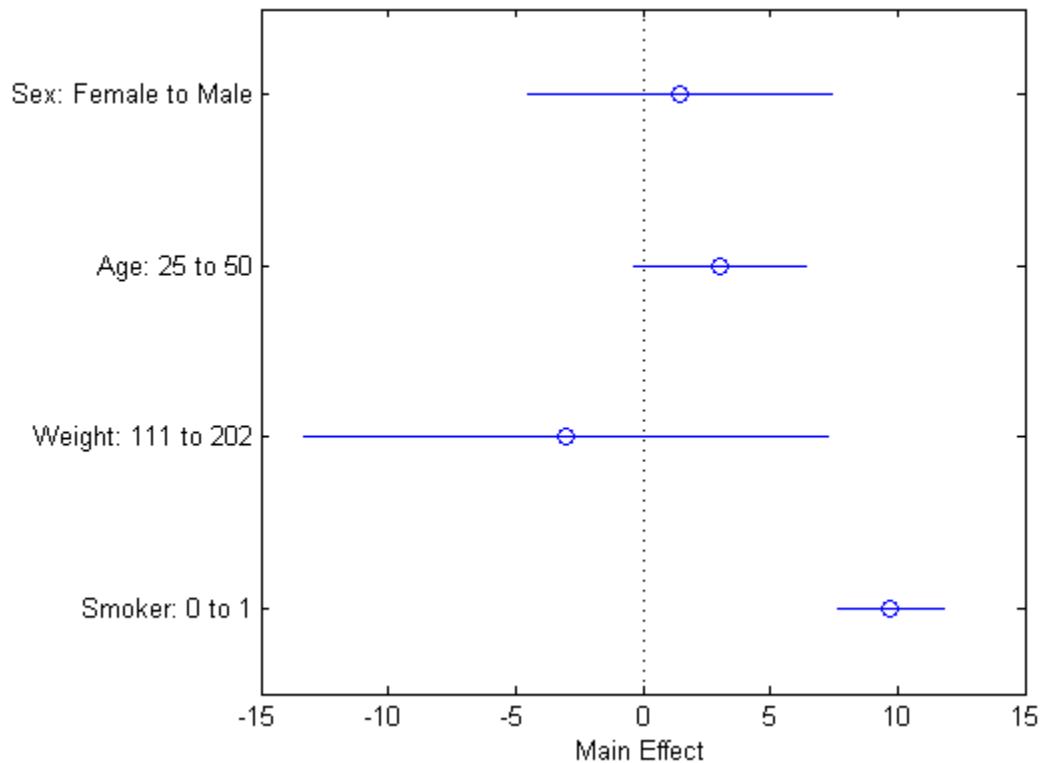
The horizontal dashed blue line in each panel shows the predicted response for the specific value of the predictor variable corresponding to the vertical dashed blue line. You can drag these lines to get the predicted response values at other predictor values, as shown next.



For example, the predicted value of the response variable is 118.3497 when a patient is female, nonsmoking, age 40.3788, and weighs 139.9545 pounds. The values in the square brackets, [114.621, 122.079], show the lower and upper limits of a 95% confidence interval for the estimated response. Note that, for a nonsmoking female patient, the expected blood pressure decreases as the weight increases, given all else is held constant.

Plot main effects.

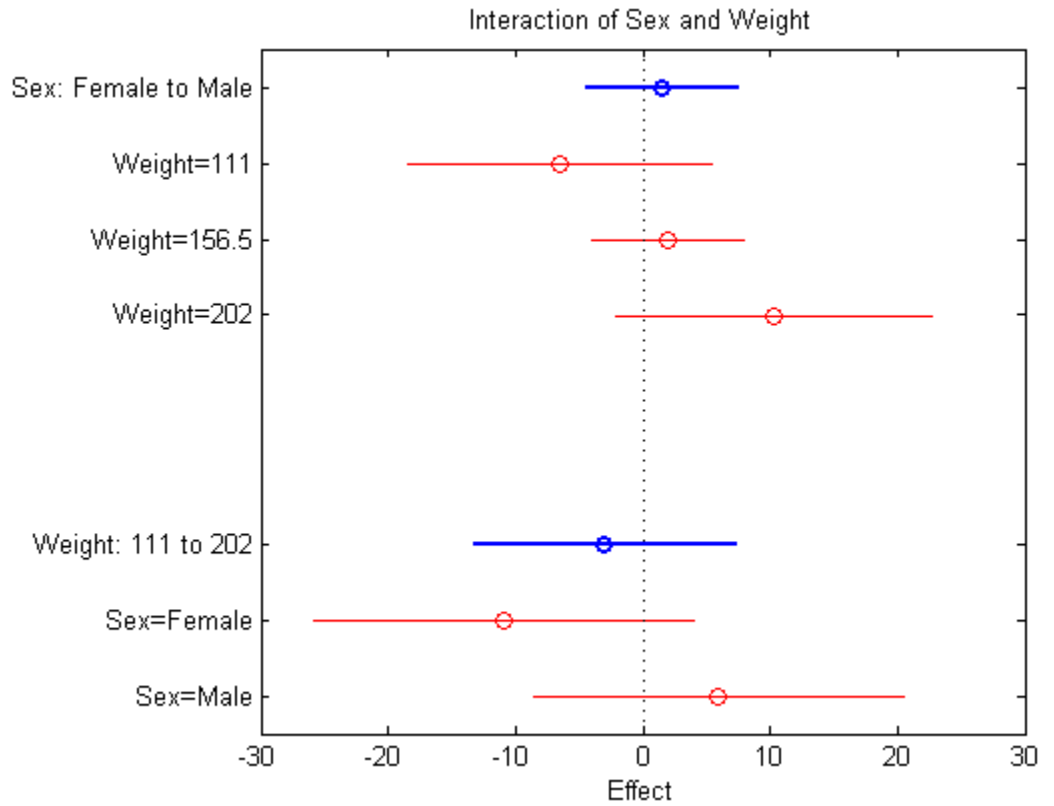
```
figure()  
plotEffects mdl
```



This plot displays the main effects. The circles show the magnitude of the effect and the blue lines show the upper and lower confidence limits for the main effect. For example, being a smoker increases the expected blood pressure by 10 units, compared to being a nonsmoker, given all else is held constant. Expected blood pressure increases about two units for males compared to females, again, given other predictors held constant. An increase in age from 25 to 50 causes an expected increase of 4 units, whereas a change in weight from 111 to 202 causes about a 4-unit decrease in the expected blood pressure, given all else held constant.

Plot interaction effects.

```
figure()  
plotInteraction(mdl, 'Sex', 'Weight')
```



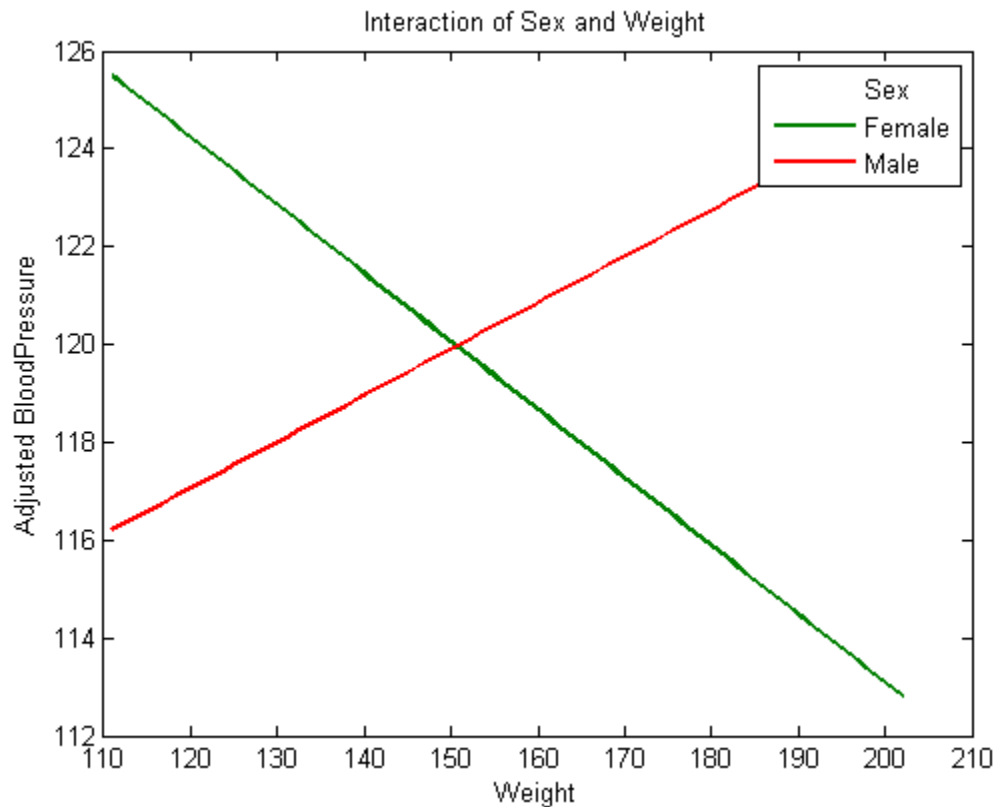
This plot displays the impact of a change in one factor given the other factor is fixed at a value.

Note Be cautious while interpreting the interaction effects. When there is not enough data on all factor combinations or the data is highly correlated, it might be difficult to determine the interaction effect of changing one factor while keeping the other fixed. In such cases, the estimated interaction effect is an extrapolation from the data.

The blue circles show the main effect of a specific term, as in the main effects plot. The red circles show the impact of a change in one term for fixed values of the other term. For example, in the bottom half of this plot, the red circles show the impact of a weight change in female and male patients, separately. You can see that an increase in a female's weight from 111 to 202 pounds causes about a 14-unit decrease in the expected blood pressure, while an increase of the same amount in the weight of a male patient causes about a 5-unit increase in the expected blood pressure, again given other predictors are held constant.

Plot prediction effects.

```
figure()  
plotInteraction mdl, 'Sex', 'Weight', 'predictions'
```



This plot shows the effect of changing one variable as the other predictor variable is held constant. In this example, the last figure shows the response variable, blood pressure, as a function of weight, when the variable sex is fixed at males and females. The lines for males and females are crossing which indicates a strong interaction between weight and sex. You can see that the expected blood pressure increases as the weight of a male patient increases, but decreases as the weight of a female patient increases.

See Also

`LinearModel` | `LinearModel.fit` | `LinearModel.stepwise` | `plotSlice` | `plotEffects` | `plotInteraction` |

Related Examples

- “Plots to Understand Predictor Effects” on page 9-26

Interpret Linear Regression Results

This example shows how to display and interpret linear regression output statistics.

Load sample data and define predictor variables.

```
load carsmall
X = [Weight,Horsepower,Acceleration];
```

Fit linear regression model.

```
lm = LinearModel.fit(X,MPG,'linear')
```

```
lm =
```

```
Linear regression model:
```

```
y ~ 1 + x1 + x2 + x3
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	47.977	3.8785	12.37	4.8957e-21
x1	-0.0065416	0.0011274	-5.8023	9.8742e-08
x2	-0.042943	0.024313	-1.7663	0.08078
x3	-0.011583	0.19333	-0.059913	0.95236

```
Number of observations: 93, Error degrees of freedom: 89
```

```
Root Mean Squared Error: 4.09
```

```
R-squared: 0.752, Adjusted R-Squared 0.744
```

```
F-statistic vs. constant model: 90, p-value = 7.38e-27
```

This linear regression outputs display shows the following.

$y \sim 1 + x_1 + x_2 + x_3$	Linear regression model in the formula form using Wilkinson notation. Here it corresponds to: $y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon.$
First column (under Estimated Coefficients)	Terms included in the model.
Estimate	Coefficient estimates for each corresponding term in the model. For example, the estimate for the constant term (intercept) is 47.977.
SE	Standard error of the coefficients.
tStat	<i>t</i> -statistic for each coefficient to test the null hypothesis that the corresponding coefficient is zero against the alternative that it is different from zero, given the other predictors in the model. Note that $tStat = Estimate/SE$. For example, the <i>t</i> -statistic for the intercept is $47.977/3.8785 = 12.37$.
pValue	<i>p</i> -value for the F statistic of the hypotheses test that the corresponding coefficient is equal to zero or not. For example, the <i>p</i> -value of the F-statistic for x_2 is greater than 0.05, so this term is not significant at the 5% significance level given the other terms in the model.
Number of observations	Number of rows without any NaN values. For example, Number of observations is 93 because the MPG data vector has 6 NaN values and one of the data vectors, Horsepower, has one NaN value for a different observation.
Error degrees of freedom	$n - p$, where n is the number of observations, and p is the number of coefficients in the model, including the intercept. For example, the model has four predictors, so the Error degrees of freedom is $93 - 4 = 89$.
Root mean squared error	Square root of the mean squared error, which estimates the standard deviation of the error distribution.

R-squared and Adjusted R-squared	Coefficient of determination and adjusted coefficient of determination, respectively. For example, the R-squared value suggests that the model explains approximately 75% of the variability in the response variable MPG.
F-statistic vs. constant model	Test statistic for the F-test on the regression model. It tests for a significant linear regression relationship between the response variable and the predictor variables.
p-value	<i>p</i> -value for the F-test on the model. For example, the model is significant with a <i>p</i> -value of 7.3816e-27.

You can request this display by using `disp`. For example, if you name your model `lm`, then you can display the outputs using `disp(lm)`.

Perform analysis of variance (ANOVA) for the model.

```
anova(lm, 'summary')
```

```
ans =
```

	SumSq	DF	MeanSq	F	pValue
Total	6004.8	92	65.269		
Model	4516	3	1505.3	89.987	7.3816e-27
Residual	1488.8	89	16.728		

This ANOVA display shows the following.

SumSq	Sum of squares for the regression model, Model, the error term, Residual, and the total, Total.
DF	Degrees of freedom for each term. Degrees of freedom is $n - 1$ for the total, $p - 1$ for the model, and $n - p$ for the error term, where n is the number of observations, and p is the number of coefficients in the model, including the intercept. For example, MPG data vector has six NaN values and one of the data vectors, Horsepower, has one NaN value for a different observation, so the total degrees of freedom is $93 - 1 = 92$. There are four coefficients in the model, so the model DF is $4 - 1 = 3$, and the DF for error term is $93 - 4 = 89$.
MeanSq	Mean squared error for each term. Note that $\text{MeanSq} = \text{SumSq}/\text{DF}$. For example, the mean squared error for the error term is $1488.8/89 = 16.728$. The square root of this value is the root mean squared error in the linear regression display, or 4.09.
F	F-statistic value, which is the same as F-statistic vs. constant model in the linear regression display. In this example, it is 89.987, and in the linear regression display this F-statistic value is rounded up to 90.
pValue	p-value for the F-test on the model. In this example, it is 7.3816e-27.

Note If there are higher-order terms in the regression model, anova partitions the model SumSq into the part explained by the higher-order terms and the rest. The corresponding F-statistics are for testing the significance of the linear terms and higher-order terms as separate groups.

If the data includes replicates, or multiple measurements at the same predictor values, then the anova partitions the error SumSq into the part for the replicates and the rest. The corresponding F-statistic is for testing the lack-of-fit by comparing the model residuals with the model-free variance estimate computed on the replicates.

See the anova method for details.

Decompose ANOVA table for model terms.

```
anova(lm)
```

```
ans =
```

	SumSq	DF	MeanSq	F	pValue
x1	563.18	1	563.18	33.667	9.8742e-08
x2	52.187	1	52.187	3.1197	0.08078
x3	0.060046	1	0.060046	0.0035895	0.95236
Error	1488.8	89	16.728		

This anova display shows the following:

First column	Terms included in the model.
SumSq	Sum of squared error for each term except for the constant.
DF	Degrees of freedom. In this example, DF is 1 for each term in the model and $n - p$ for the error term, where n is the number of observations, and p is the number of coefficients in the model, including the intercept. For example, the DF for the error term in this model is $93 - 4 = 89$. If any of the variables in the model is a categorical variable, the DF for that variable is the number of indicator variables created for its categories (number of categories - 1).
MeanSq	Mean squared error for each term. Note that $\text{MeanSq} = \text{SumSq}/\text{DF}$. For example, the mean squared error for the error term is $1488.8/89 = 16.728$.

F	F-values for each coefficient. The F-value is the ratio of the mean squared of each term and mean squared error, that is, $F = \text{MeanSq}(x_i) / \text{MeanSq}(\text{Error})$. Each F-statistic has an F distribution, with the numerator degrees of freedom, DF value for the corresponding term, and the denominator degrees of freedom, $n - p$. n is the number of observations, and p is the number of coefficients in the model. In this example, each F-statistic has an $F_{(1, 89)}$ distribution.
pValue	p -value for each hypothesis test on the coefficient of the corresponding term in the linear model. For example, the p -value for the F-statistic coefficient of x_2 is 0.08078, and is not significant at the 5% significance level given the other terms in the model.

Display coefficient confidence intervals.

```
coefCI(lm)
```

```
ans =
```

```

40.2702    55.6833
-0.0088   -0.0043
-0.0913    0.0054
-0.3957    0.3726

```

The values in each row are the lower and upper confidence limits, respectively, for the default 95% confidence intervals for the coefficients. For example, the first row shows the lower and upper limits, 40.2702 and 55.6833, for the intercept, β_0 . Likewise, the second row shows the limits for β_1 and so on. Confidence intervals provide a measure of precision for linear regression coefficient estimates. A $100(1-\alpha)\%$ confidence interval gives the range the corresponding regression coefficient will be in with $100(1-\alpha)\%$ confidence.

You can also change the confidence level. Find the 99% confidence intervals for the coefficients.

```
coefCI(lm,0.01)
```

```
ans =
```

```
37.7677    58.1858
-0.0095    -0.0036
-0.1069     0.0211
-0.5205     0.4973
```

Perform hypothesis test on coefficients.

Test the null hypothesis that all predictor variable coefficients are equal to zero versus the alternate hypothesis that at least one of them is different from zero.

```
[p,F,d] = coefTest(lm)
```

```
p =
```

```
7.3816e-27
```

```
F =
```

```
89.9874
```

```
d =
```

```
3
```

Here, `coefTest` performs an F-test for the hypothesis that all regression coefficients (except for the intercept) are zero versus at least one differs from zero, which essentially is the hypothesis on the model. It returns `p`, the p -value, `F`, the F-statistic, and `d`, the numerator degrees of freedom. The F-statistic and p -value are the same as the ones in the linear regression display and ANOVA for the model. The degrees of freedom is $4 - 1 = 3$ because there are four predictors (including the intercept) in the model.

Now, perform a hypothesis test on the coefficients of the first and second predictor variables.

```
H = [0 1 0 0; 0 0 1 0];
[p,F,d] = coefTest(lm,H)
```

p =

5.1702e-23

F =

96.4873

d =

2

The numerator degrees of freedom is the number of coefficients tested, which is 2 in this example. The results indicate that at least one of β_2 and β_3 differs from zero.

See Also

[LinearModel](#) | [LinearModel.fit](#) | [LinearModel.stepwise](#) | [anova](#) |

Related Examples

- “Examine Quality and Adjust the Fitted Model” on page 9-17

Concepts

- “Linear Regression Output and Diagnostic Statistics” on page 9-68

Linear Regression Output and Diagnostic Statistics

Summary of Measures

Name	LinearModel	regstats
Cook's Distance	CooksDistance and cookd	cookd
Coefficient Confidence Intervals	coefCI	N/A
Coefficient Covariance	CoefficientCovariance	covb
Coefficient of Determination (R-squared)	Rsquared: Ordinary, Adjusted	rsquare, adjrsquare
Delete-1 Change in Covariance (covratio)	CovRatio	covratio
Delete-1 Scaled Difference in Coefficient Estimates (Dfbetas)	Dfbetas	dfbetas
Delete-1 Scaled Change in Fitted Values (Dffits)	Dffits	dffits
Delete-1 Variance (S2_i)	S2_i	s2_i
Durbin-Watson Test	dwtest	dwstat
F-statistic	Fstat	fstat
Hat Matrix	HatMatrix	hatmat
Leverage	Leverage	leverage
Residuals	Residuals: Raw, Pearson, Studentized, Standardized	r, studres, standres
t-statistic	tstats	tstat

Cook's Distance

Purpose

Cook's distance is useful for identifying outliers in the X values (observations for predictor variables). It also shows the influence of each observation on the fitted response values. An observation with Cook's distance larger than three times the mean Cook's distance might be an outlier.

Definition

Cook's distance is the scaled change in fitted values. Each element in `CooksDistance` is the normalized change in the vector of coefficients due to the deletion of an observation. The Cook's distance, D_i , of observation i is

$$D_i = \frac{\sum_{j=1}^n (\hat{y}_j - \hat{y}_{j(i)})^2}{p \text{MSE}},$$

where

- \hat{y}_j is the j th fitted response value.
- $\hat{y}_{j(i)}$ is the j th fitted response value, where the fit does not include observation i .
- MSE is the mean squared error.
- p is the number of coefficients in the regression model.

Cook's distance is algebraically equivalent to the following expression:

$$D_i = \frac{r_i^2}{p \text{MSE}} \left(\frac{h_{ii}}{(1 - h_{ii})^2} \right),$$

where r_i is the i th residual, and h_{ii} is the i th leverage value.

`CooksDistance` is an n -by-1 column vector in the `Diagnostics` dataset array of the `LinearModel` object.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Display the Cook's distance values by indexing into the property using dot notation,

```
mdl.Diagnostics.CooksDistance
```

- Plot the Cook's distance values using

```
plotDiagnostics(mdl, 'cookd')
```

For details, see the `plotDiagnostics` method of the `LinearModel` class.

Example

Load the sample data and define the independent and response variables.

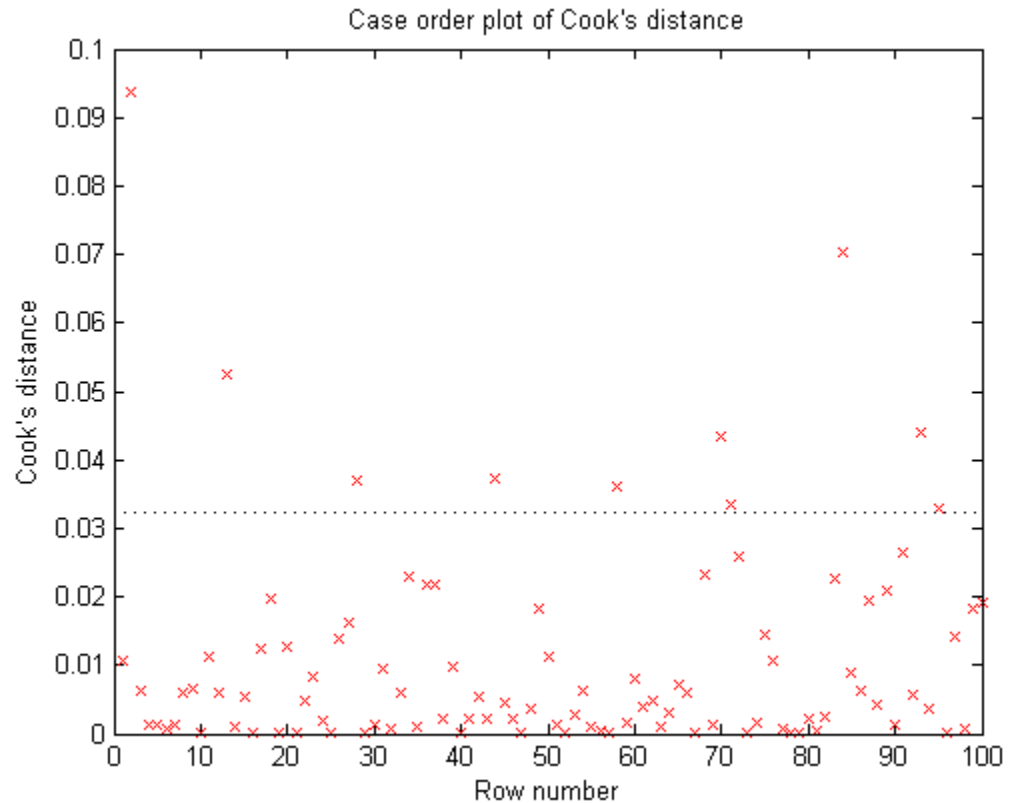
```
load hospital
X = double(hospital(:,2:5));
y = hospital.BloodPressure(:,1);
```

Fit the linear regression model.

```
mdl = LinearModel.fit(X,y);
```

Plot the Cook's distance values.

```
plotDiagnostics(mdl, 'cookd')
```



The dashed line in the figure corresponds to the recommended threshold value, $3 \times \text{mean}(\text{mdl.Diagnostics.CooksDistance})$. The plot has some observations with Cook's distance values greater than the threshold value, which for this example is $3 \times (0.0108) = 0.0324$. In particular, there are two Cook's distance values that are relatively higher than the others, which exceed the threshold value. You might want to find and omit these from your data and rebuild your model.

Find the observations with Cook's distance values that exceed the threshold value.

```
find((mdl.Diagnostics.CooksDistance)>3*mean(mdl.Diagnostics.CooksDistance))
```

```
ans =  
    2  
   13  
   28  
   44  
   58  
   70  
   71  
   84  
   93  
   95
```

Find the observations with Cook's distance values that are relatively larger than the other observations with Cook's distances exceeding the threshold value.

```
find((mdl.Diagnostics.CooksDistance)>5*mean(mdl.Diagnostics.CooksDistance))  
ans =  
    2  
   84
```

Return to Summary of Measures.

Coefficient Confidence Intervals

Purpose

The coefficient confidence intervals provide a measure of precision for linear regression coefficient estimates. A 100(1- α)% confidence interval gives the range that the corresponding regression coefficient will be in with 100(1- α)% confidence.

Definition

The 100*(1- α)% confidence intervals for linear regression coefficients are

$$b_i \pm t_{(1-\alpha/2, n-p)} SE(b_i),$$

where b_i is the coefficient estimate, $SE(b_i)$ is the standard error of the coefficient estimate, and $t_{(1-\alpha/2, n-p)}$ is the $100(1-\alpha/2)$ percentile of t -distribution with $n - p$ degrees of freedom. n is the number of observations and p is the number of regression coefficients.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can obtain the default 95% confidence intervals for coefficients using

```
coefCI(mdl)
```

You can also change the confidence level using

```
coefCI(mdl, alpha)
```

For details, see the `coefCI` and `coefTest` methods of `LinearModel` class.

Example

Load the sample data and fit a linear regression model.

```
load hald
mdl = LinearModel.fit(ingredients, heat);
```

Display the 95% coefficient confidence intervals.

```
coefCI(mdl)

ans =

    -99.1786    223.9893
     -0.1663     3.2685
     -1.1589     2.1792
     -1.6385     1.8423
     -1.7791     1.4910
```

The values in each row are the lower and upper confidence limits, respectively, for the default 95% confidence intervals for the coefficients. For example, the first row shows the lower and upper limits, -99.1786 and 223.9893 , for the intercept, β_0 . Likewise, the second row shows the limits for β_1 and so on.

Display the 90% confidence intervals for the coefficients ($\alpha = 0.1$).

```
coefCI(md1, 0.1)
```

```
ans =
```

```
-67.8949  192.7057  
  0.1662   2.9360  
 -0.8358   1.8561  
 -1.3015   1.5053  
 -1.4626   1.1745
```

The confidence interval limits become narrower as the confidence level decreases.

Return to Summary of Measures.

Coefficient Covariance

Purpose

Estimated coefficient variances and covariances capture the precision of regression coefficient estimates. The coefficient variances and their square root, the standard errors, are useful in testing hypotheses for coefficients.

Definition

The estimated covariance matrix is

$$\Sigma = MSE(XX)^{-1},$$

where MSE is the mean squared error, and X is the matrix of observations on the predictor variables. `CoefficientCovariance`, a property of the fitted model, is a p -by- p covariance matrix of regression coefficient estimates. p is the number of coefficients in the regression model. The diagonal elements are the variances of the individual coefficients.

How To

After obtaining a fitted model, say, `md1`, using `LinearModel.fit` or `LinearModel.stepwise`, you can display the coefficient covariances using

```
mdl.CoefficientCovariance
```

Example

Load the sample data and define the predictor and response variables.

```
load hospital
y = hospital.BloodPressure(:,1);
X = double(hospital(:,2:5));
```

Fit a linear regression model.

```
mdl = LinearModel.fit(X,y);
```

Display the coefficient covariance matrix.

```
mdl.CoefficientCovariance
```

```
ans =
```

27.5113	11.0027	-0.1542	-0.2444	0.2702
11.0027	8.6864	0.0021	-0.1547	-0.0838
-0.1542	0.0021	0.0045	-0.0001	-0.0029
-0.2444	-0.1547	-0.0001	0.0031	-0.0026
0.2702	-0.0838	-0.0029	-0.0026	1.0829

Return to Summary of Measures.

Coefficient of Determination (R-Squared)

Purpose

Coefficient of determination (R-squared) indicates the proportionate amount of variation in the response variable y explained by the independent variables X in the linear regression model. The larger the R-squared is, the more variability is explained by the linear regression model.

Definition

R-squared is the proportion of the total sum of squares explained by the model. `Rsquared`, a property of the fitted model, is a structure with two fields:

- Ordinary — Ordinary (unadjusted) R-squared

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}.$$

- Adjusted — R-squared adjusted for the number of coefficients

$$R_{adj}^2 = 1 - \left(\frac{n-1}{n-p} \right) \frac{SSE}{SST}.$$

SSE is the sum of squared error, *SSR* is the sum of squared regression, *SST* is the sum of squared total, *n* is the number of observations, and *p* is the number of regression coefficients (including the intercept). Because R-squared increases with added predictor variables in the regression model, the adjusted R-squared adjusts for the number of predictor variables in the model. This makes it more useful for comparing models with a different number of predictors.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can obtain either R-squared value as a scalar by indexing into the property using dot notation, for example,

```
mdl.Rsquared.Ordinary  
mdl.Rsquared.Adjusted
```

You can also obtain the SSE, SSR, and SST using the properties with the same name.

```
mdl.SSE  
mdl.SSR  
mdl.SST
```

Example

Load the sample data and define the response and independent variables.

```
load hospital  
y = hospital.BloodPressure(:,1);  
X = double(hospital(:,2:5));
```

Fit a linear regression model.

```
mdl = LinearModel.fit(X,y)
```

```
mdl =
```

```
Linear regression model:  
y ~ 1 + x1 + x2 + x3 + x4
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	117.4	5.2451	22.383	1.1667e-39
x1	0.88162	2.9473	0.29913	0.76549
x2	0.08602	0.06731	1.278	0.20438
x3	-0.016685	0.055714	-0.29947	0.76524
x4	9.884	1.0406	9.498	1.9546e-15

Number of observations: 100, Error degrees of freedom: 95

Root Mean Squared Error: 4.81

R-squared: 0.508, Adjusted R-Squared 0.487

F-statistic vs. constant model: 24.5, p-value = 5.99e-14

The R-squared and adjusted R-squared values are 0.508 and 0.487, respectively. Model explains about 50% of the variability in the response variable.

Access the R-squared and adjusted R-squared values using the property of the fitted `LinearModel` object.

```
mdl.Rsquared.Ordinary
```

```
ans =
```

```
0.5078
```

```
mdl.Rsquared.Adjusted
```

```
ans =
```

```
0.4871
```

The adjusted R-squared value is smaller than the ordinary R-squared value.

[Return to Summary of Measures.](#)

Delete-1 Change in Covariance (covratio)

Purpose

Delete-1 change in covariance (covratio) identifies the observations that are influential in the regression fit. An influential observation is one where its exclusion from the model might significantly alter the regression function. Values of covratio larger than $1 + 3*p/n$ or smaller than $1 - 3*p/n$ indicate influential points, where p is the number of regression coefficients, and n is the number of observations.

Definition

The covratio statistic is the ratio of the determinant of the coefficient covariance matrix with observation i deleted to the determinant of the covariance matrix for the full model:

$$\text{covratio} = \frac{\det\{MSE(i)[X'(i)X(i)]^{-1}\}}{\det[MSE(XX)^{-1}]}$$

CovRatio is an n -by-1 vector in the `Diagnostics` dataset array of the fitted `LinearModel` object. Each element is the ratio of the generalized variance of the estimated coefficients when the corresponding element is deleted to the generalized variance of the coefficients using all the data.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Display the `CovRatio` by indexing into the property using dot notation
`mdl.Diagnostics.CovRatio`
- Plot the delete-1 change in covariance using

```
plotDiagnostics mdl, 'CovRatio')
```

For details, see the `plotDiagnostics` method of the `LinearModel` class.

Example

Load the sample data and define the response and predictor variables.

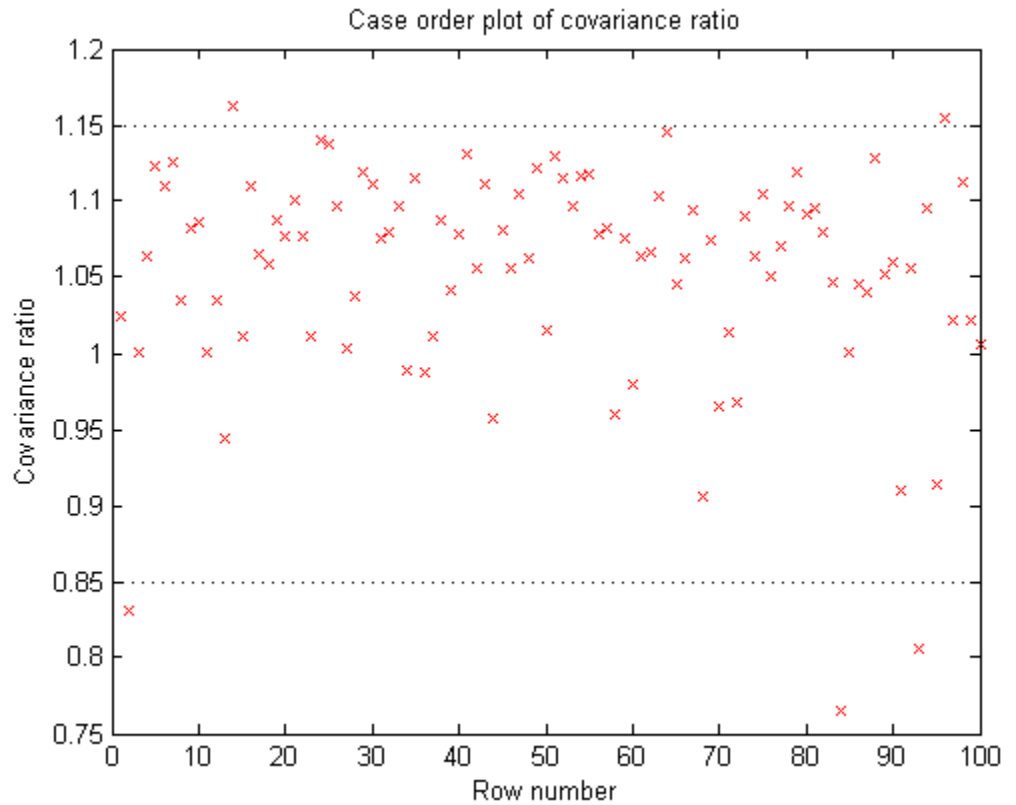
```
load hospital  
y = hospital.BloodPressure(:,1);  
X = double(hospital(:,2:5));
```

Fit a linear regression model.

```
mdl = LinearModel.fit(X,y);
```

Plot the `CovRatio` statistics.

```
plotDiagnostics(mdl, 'CovRatio')
```



For this example, the threshold limits are $1 + 3*5/100 = 1.15$ and $1 - 3*5/100 = 0.85$. There are a few points beyond the limits, which might be influential points.

Find the observations that are beyond the limits.

```
find((mdl.Diagnostics.CovRatio)>1.15|(mdl.Diagnostics.CovRatio)<0.85)
```

ans =

- 2
- 14
- 84

93

96

[Return to Summary of Measures.](#)

Delete-1 Scaled Difference in Coefficient Estimates (Dfbetas)

Purpose

The sign of a delete-1 scaled difference in coefficient estimate (Dfbetas) for coefficient j and observation i indicates whether that observation causes an increase or decrease in the estimate of the regression coefficient. The absolute value of a Dfbetas indicates the magnitude of the difference relative to the estimated standard deviation of the regression coefficient. A Dfbetas value larger than $3/\sqrt{n}$ in absolute value indicates that the observation has a large influence on the corresponding coefficient.

Definition

Dfbetas for coefficient j and observation i is the ratio of the difference in the estimate of coefficient j using all observations and the one obtained by removing observation i , and the standard error of the coefficient estimate obtained by removing observation i . The Dfbetas for coefficient j and observation i is

$$Dfbetas_{ij} = \frac{b_j - b_{j(i)}}{\sqrt{MSE_{(i)}(1 - h_{ii})}},$$

where b_j is the estimate for coefficient j , $b_{j(i)}$ is the estimate for coefficient j by removing observation i , $MSE_{(i)}$ is the mean squared error of the regression fit by removing observation i , and h_{ii} is the leverage value for observation i . Dfbetas is an n -by- p matrix in the `Diagnostics` dataset array of the fitted `LinearModel` object. Each cell of Dfbetas corresponds to the Dfbetas value for the corresponding coefficient obtained by removing the corresponding observation.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can obtain the `Dfbetas` values as an n -by- p matrix by indexing into the property using dot notation,

```
mdl.Diagnostics.Dfbetas
```

Example

Load the sample data and define the response and independent variables.

```
load hospital
y = hospital.BloodPressure(:,1);
X = double(hospital(:,2:5));
```

Fit a linear regression model.

```
mdl = LinearModel.fit(X,y);
```

Find the `Dfbetas` values that are high in absolute value.

```
[row,col] = find(abs(mdl.Diagnostics.Dfbetas)>3/sqrt(100));
disp([row col])
```

```
 2     1
28     1
84     1
93     1
 2     2
13     3
84     3
 2     4
84     4
```

Return to [Summary of Measures](#).

Delete-1 Scaled Change in Fitted Values (Dffits)

Purpose

The delete-1 scaled change in fitted values (Dffits) show the influence of each observation on the fitted response values. Dffits values with an absolute value larger than $2 \cdot \sqrt{p/n}$ might be influential.

Definition

Dffits for observation i is

$$Dffits_i = sr_i \sqrt{\frac{h_{ii}}{1 - h_{ii}}},$$

where sr_i is the studentized residual, and h_{ii} is the leverage value of the fitted `LinearModel` object. Dffits is an n -by-1 column vector in the `Diagnostics` dataset array of the fitted `LinearModel` object. Each element in Dffits is the change in the fitted value caused by deleting the corresponding observation and scaling by the standard error.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Display the Dffits values by indexing into the property using dot notation

```
mdl.Diagnostics.Dffits
```

- Plot the delete-1 scaled change in fitted values using

```
plotDiagnostics(mdl, 'Dffits')
```

For details, see the `plotDiagnostics` method of the `LinearModel` class for details.

Example

Load the sample data and define the response and independent variables.

```
load hospital
```

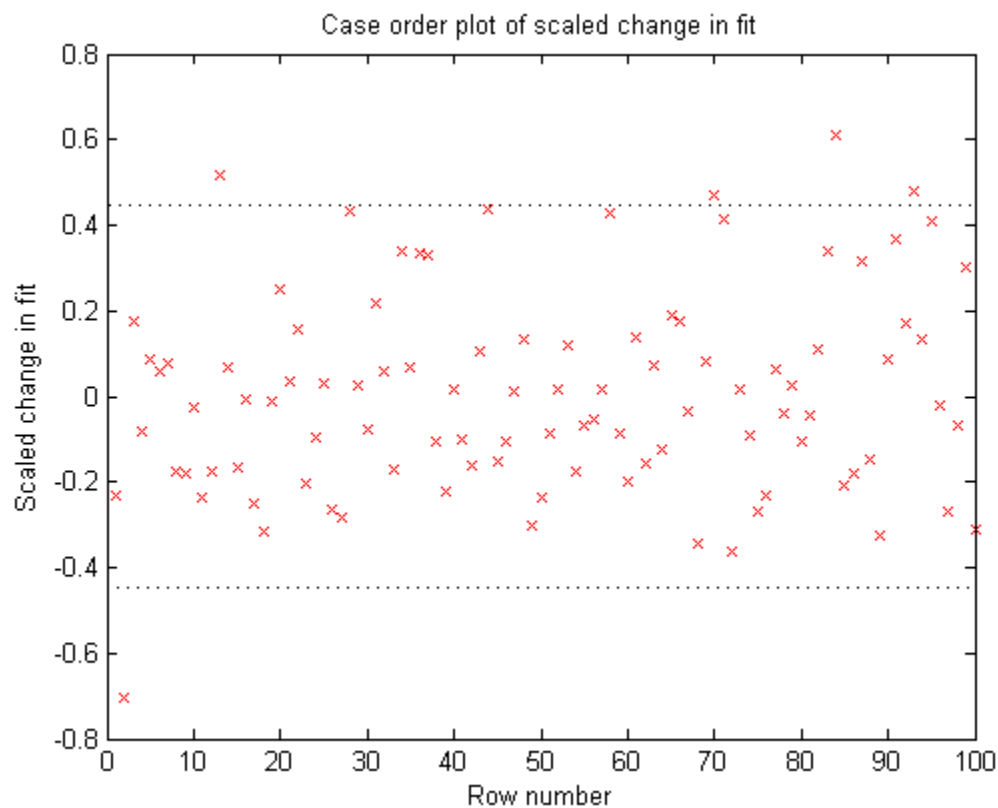
```
y = hospital.BloodPressure(:,1);  
X = double(hospital(:,2:5));
```

Fit a linear regression model.

```
mdl = LinearModel.fit(X,y);
```

Plot the Dffits values.

```
plotDiagnostics(mdl,'Dffits')
```



The influential threshold limit for the absolute value of Dffits in this example is $2 \cdot \sqrt{5/100} = 0.45$. Again, there are some observations with Dffits values beyond the recommended limits.

Find the Dffits values that are large in absolute value.

```
find(abs(md1.Diagnostics.Dffits)>2*sqrt(4/100))
```

```
ans =
```

```

     2
    13
    28
    44
    58
    70
    71
    84
    93
    95

```

Return to Summary of Measures.

Delete-1 Variance ($S2_i$)

Purpose

The delete-1 variance ($S2_i$) shows how the mean squared error changes when an observation is removed from the data set. You can compare the $S2_i$ values with the value of the mean squared error.

Definition

$S2_i$ is a set of residual variance estimates obtained by deleting each observation in turn. The $S2_i$ value for observation i is

$$S2_i = MSE_{(i)} = \frac{\sum_{j \neq i}^n [y_j - y_{j(i)}]^2}{n - p - 1},$$

where y_j is the j th observed response value. `S2_i` is an n -by-1 vector in the `Diagnostics` dataset array of the fitted `LinearModel` object. Each element in `S2_i` is the mean squared error of the regression obtained by deleting that observation.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Display the `S2_i` vector by indexing into the property using dot notation

```
mdl.Diagnostics.S2_i
```

- Plot the delete-1 variance values using

```
plotDiagnostics(mdl, 'S2_i')
```

For details, see the `plotDiagnostics` method of the `LinearModel` class.

Example

Load the sample data and define the response and independent variables.

```
load hospital
y = hospital.BloodPressure(:,1);
X = double(hospital(:,2:5));
```

Fit a linear regression model.

```
mdl = LinearModel.fit(X,y);
```

Display the MSE value for the model.

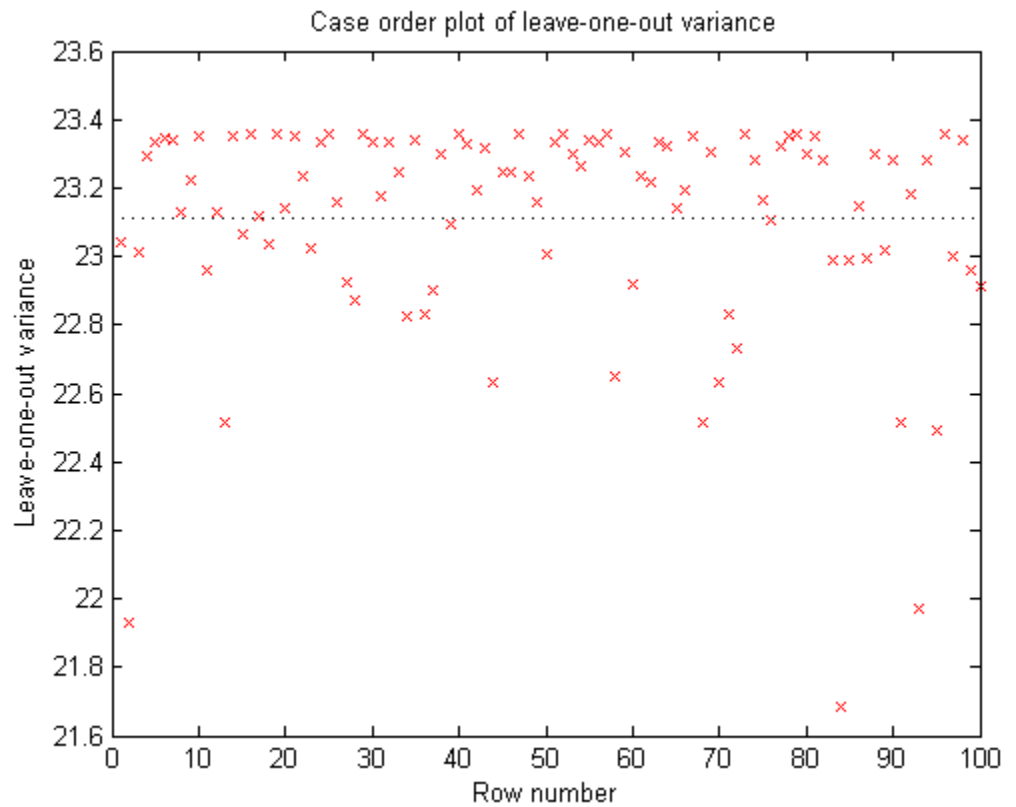
```
mdl.MSE
```

```
ans =
```

```
23.1140
```

Plot the `S2_i` values.

```
plotDiagnostics(mdl, 'S2_i')
```



This plot makes it easy to compare the S^2_i values to the MSE value of 23.114, indicated by the horizontal dashed lines. You can see how deleting one observation changes the error variance.

[Return to Summary of Measures.](#)

Durbin-Watson Test

Purpose

The Durbin-Watson test assesses whether there is autocorrelation among the residuals or not.

Definition

The Durbin-Watson test statistic, DW , is

$$DW = \frac{\sum_{i=1}^{n-1} (r_{i+1} - r_i)^2}{\sum_{i=1}^n r_i^2}.$$

Here, r_i is the i th raw residual, and n is the number of observations.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can perform the Durbin-Watson test using

```
dwtest(mdl)
```

For details, see the `dwtest` method of the `LinearModel` class.

Example

Load the sample data and fit a linear regression model.

```
load hald  
mdl = LinearModel.fit(ingredients,heat);
```

Perform a two-sided Durbin-Watson test to determine if there is any autocorrelation among the residuals of the linear model, `mdl`.

```
[p,DW] = dwtest(mdl,'exact','both')
```

```
p =
```

```
0.6285
```

```
DW =
```

```
2.0526
```


The value of the Durbin-Watson test statistic is 2.0526. The p -value of 0.6285 suggest that the residuals are not autocorrelated.

F-statistic

Purpose

In linear regression, the F-statistic is the test statistic for the analysis of variance (ANOVA) approach to test the significance of the model or the components in the model.

Definition

The F-statistic in the linear model output display is the test statistic for testing the statistical significance of the model. The F-statistic values in the anova display are for assessing the significance of the terms or components in the model.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Find the F-statistic vs. constant model in the output display or by using

```
disp(mdl)
```

- Display the ANOVA for the model using

```
anova(mdl, 'summary')
```

- Obtain the F-statistic values for the components, except for the constant term using

```
anova(mdl)
```

For details, see the `anova` method of the `LinearModel` class.

Example

Load the sample data.

```
load carbig
ds = dataset(Acceleration,Cylinders,Weight,MPG);
ds.Cylinders = ordinal(Cylinders);
```

Fit a linear regression model.

```
mdl = LinearModel.fit(ds, 'MPG~Acceleration*Weight+Cylinders+Weight^2')
```

```
mdl =
```

Linear regression model:

```
MPG ~ 1 + Cylinders + Acceleration*Weight + Weight^2
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	50.816	7.5669	6.7156	6.661e-
Acceleration	0.023343	0.33931	0.068796	0.945
Cylinders_4	7.167	2.0596	3.4798	0.00055
Cylinders_5	10.963	3.1299	3.5028	0.000513
Cylinders_6	4.7415	2.1257	2.2306	0.0262
Cylinders_8	5.057	2.2981	2.2005	0.0283
Weight	-0.017497	0.0034674	-5.0461	6.9371e-
Acceleration:Weight	7.0745e-05	0.00011171	0.6333	0.526
Weight^2	1.5767e-06	3.6909e-07	4.2719	2.4396e-

Number of observations: 398, Error degrees of freedom: 389

Root Mean Squared Error: 4.02

R-squared: 0.741, Adjusted R-Squared 0.736

F-statistic vs. constant model: 139, p-value = 2.94e-109

The F-statistic of the linear fit versus the constant model is 139, with a p -value of 2.94e-109. The model is significant at the 5% significance level. The R-squared value of 0.741 means the model explains about 74% of the variability in the response.

Display the ANOVA table for the fitted model.

```
anova mdl, 'summary'
```

```
ans =
```

	SumSq	DF	MeanSq	F	pValue
Total	24253	397	61.09		
Model	17981	8	2247.6	139.41	2.9432e-109
. Linear	17667	6	2944.4	182.63	7.5446e-110
. Nonlinear	314.36	2	157.18	9.7492	7.3906e-05
Residual	6271.6	389	16.122		
. Lack of fit	6267.1	387	16.194	7.1973	0.12968
. Pure error	4.5	2	2.25		

This display separates the variability in the model into linear and nonlinear terms. Since there are two non-linear terms ($Weight^2$ and the interaction between *Weight* and *Acceleration*), the nonlinear degrees of freedom in the DF column is 2. There are six linear terms in the model (four *Cylinders* indicator variables, *Weight*, and *Acceleration*). The corresponding F-statistics in the F column are for testing the significance of the linear and nonlinear terms as separate groups.

The residual term is also separated into two parts; first is the error due to the lack of fit, and second is the pure error independent from the model, obtained from the replicated observations. The corresponding F-statistics in the F column are for testing the lack of fit, that is, whether the proposed model is an adequate fit or not.

Display the ANOVA table for the model terms.

```
anova mdl
```

```
ans =
```

	SumSq	DF	MeanSq	F	pValue
Acceleration	104.99	1	104.99	6.5122	0.011095
Cylinders	408.94	4	102.23	6.3412	5.9573e-05
Weight	2187.5	1	2187.5	135.68	4.1974e-27
Acceleration:Weight	6.4662	1	6.4662	0.40107	0.52691
Weight^2	294.22	1	294.22	18.249	2.4396e-05

Error	6271.6	389	16.122
-------	--------	-----	--------

This display decomposes the ANOVA table into the model terms. The corresponding F-statistics in the F column are for assessing the statistical significance of each term. The F-test for `Cylinders` test whether at least one of the coefficients of indicator variables for cylinders categories is different from zero or not. That is, whether different numbers of cylinders have a significant effect on MPG or not. The degrees of freedom for each model term is the numerator degrees of freedom for the corresponding F-test. Most of the terms have 1 degree of freedom, but the degrees of freedom for `Cylinders` is 4. Because there are four indicator variables for this term.

[Return to Summary of Measures.](#)

Hat Matrix

Purpose

The hat matrix provides a measure of leverage. It is useful for investigating whether one or more observations are outlying with regard to their X values, and therefore might be excessively influencing the regression results.

Definition

The hat matrix is also known as the *projection matrix* because it projects the vector of observations, y , onto the vector of predictions, \hat{y} , thus putting the "hat" on y . The hat matrix H is defined in terms of the data matrix X :

$$H = X(X^T X)^{-1} X^T$$

and determines the fitted or predicted values since

$$\hat{y} = Hy = Xb.$$

The diagonal elements of H , h_{ii} , are called leverages and satisfy

$$0 \leq h_{ii} \leq 1$$

$$\sum_{i=1}^n h_{ii} = p,$$

where p is the number of coefficients, and n is the number of observations (rows of X) in the regression model. `HatMatrix` is an n -by- n matrix in the `Diagnostics` dataset array.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Display the `HatMatrix` by indexing into the property using dot notation

```
mdl.Diagnostics.HatMatrix
```

When n is large, `HatMatrix` might be computationally expensive. In those cases, you can obtain the diagonal values directly, using

```
mdl.Diagnostics.Leverage
```

[Return to Summary of Measures.](#)

Leverage

Purpose

Leverage is a measure of the effect of a particular observation on the regression predictions due to the position of that observation in the space of the inputs. In general, the farther a point is from the center of the input space, the more leverage it has. Because the sum of the leverage values is p , an observation i can be considered as an outlier if its leverage substantially exceeds the mean leverage value, p/n , for example, a value larger than $2 * p/n$.

Definition

The leverage of observation i is the value of the i th diagonal term, h_{ii} , of the hat matrix, H , where

$$H = X(X^T X)^{-1} X^T.$$

The diagonal terms satisfy

$$0 \leq h_{ii} \leq 1$$

$$\sum_{i=1}^n h_{ii} = p,$$

where p is the number of coefficients in the regression model, and n is the number of observations. The minimum value of h_{ii} is $1/n$ for a model with a constant term. If the fitted model goes through the origin, then the minimum leverage value is 0 for an observation at $x = 0$.

It is possible to express the fitted values, \hat{y} , by the observed values, y , since

$$\hat{y} = Hy = Xb.$$

Hence, h_{ii} expresses how much the observation y_i has impact on \hat{y}_i . A large value of h_{ii} indicates that the i th case is distant from the center of all X values for all n cases and has more leverage. Leverage is an n -by-1 column vector in the Diagnostics dataset array.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Display the Leverage vector by indexing into the property using dot notation

```
mdl.Diagnostics.Leverage
```

- Plot the leverage for the values fitted by your model using

```
plotDiagnostics(mdl)
```

See the `plotDiagnostics` method of the `LinearModel` class for details.

Example

Load the sample data and define the response and independent variables.

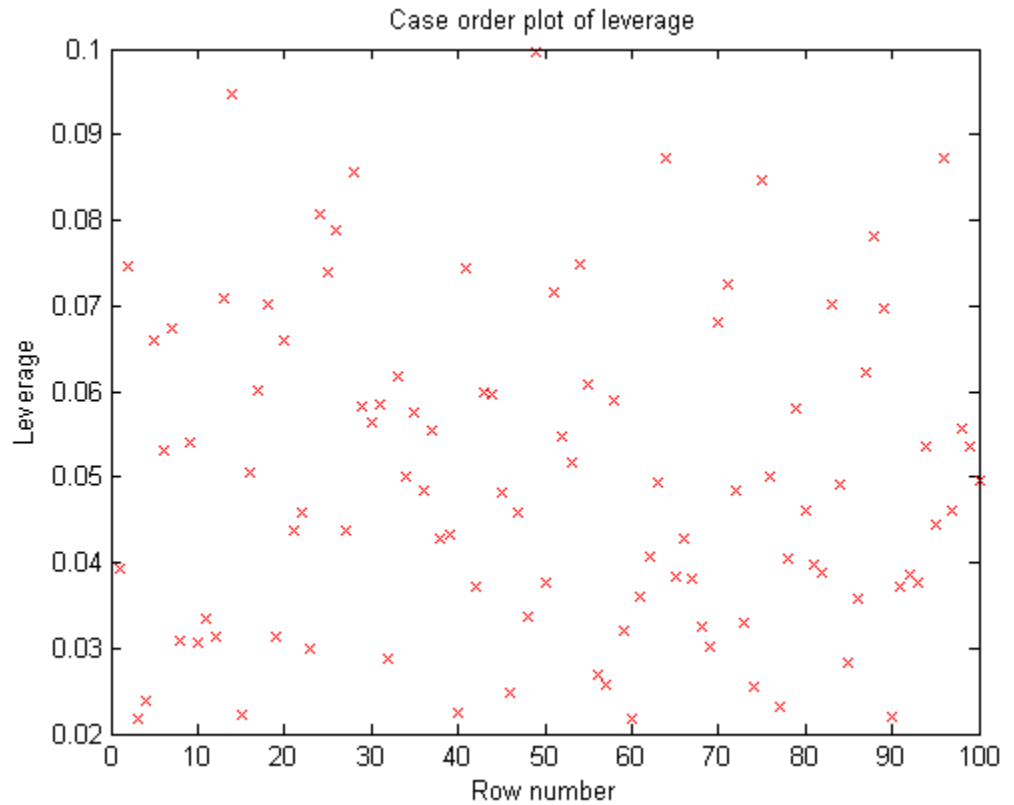
```
load hospital  
y = hospital.BloodPressure(:,1);  
X = double(hospital(:,2:5));
```

Fit a linear regression model.

```
mdl = LinearModel.fit(X,y);
```

Plot the leverage values.

```
plotDiagnostics(mdl)
```



For this example, the recommended threshold value is $2*5/100 = 0.1$. There is no indication of high leverage observations.

Return to Summary of Measures.

Residuals

Purpose

Residuals are useful for detecting outlying y values and checking the linear regression assumptions with respect to the error term in the regression model. High-leverage observations have smaller residuals because they often shift

the regression line or surface closer to them. You can also use residuals to detect some forms of heteroscedasticity and autocorrelation.

Definition

The **Residuals** matrix is an n -by-4 dataset array containing a table of four types of residuals, with one row for each observation.

Raw Residuals. Observed minus fitted values, that is,

$$r_i = y_i - \hat{y}_i.$$

Pearson Residuals. Raw residuals divided by the root mean squared error, that is,

$$pr_i = \frac{r_i}{\sqrt{MSE}},$$

where r_i is the raw residual and MSE is the mean squared error.

Standardized Residuals. Standardized residuals are raw residuals divided by their estimated standard deviation. The standardized residual for observation i is

$$st_i = \frac{r_i}{\sqrt{MSE(1 - h_{ii})}},$$

where MSE is the mean squared error and h_{ii} is the leverage value for observation i .

Studentized Residuals. Studentized residuals are the raw residuals divided by an independent estimate of the residual standard deviation. The residual for observation i is divided by an estimate of the error standard deviation based on all observations except for observation i .

$$sr_i = \frac{r_i}{\sqrt{MSE_{(i)}(1 - h_{ii})}},$$

where $MSE_{(i)}$ is the mean squared error of the regression fit calculated by removing observation i , and h_{ii} is the leverage value for observation i . The studentized residual sr_i has a t -distribution with $n - p - 1$ degrees of freedom.

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Find the `Residuals` dataset array under `mdl` object.
- Obtain any of these columns as a vector by indexing into the property using dot notation, for example,

```
mdl.Residuals.Raw
```

- Plot any of the residuals for the values fitted by your model using

```
plotResiduals(mdl)
```

For details, see the `plotResiduals` method of the `LinearModel` class.

Example

Load the sample data and store the independent and response variables in a dataset array.

```
load imports-85
ds = dataset(X(:,7),X(:,8),X(:,9),X(:,15), 'Varnames', ...
{'curb_weight', 'engine_size', 'bore', 'price'});
```

Fit a linear regression model.

```
mdl = LinearModel.fit(ds)
```

```
mdl =
```

Linear regression model:

```
price ~ 1 + curb_weight + engine_size + bore
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	64.095	3.703	17.309	2.0481e-41

curb_weight	-0.0086681	0.0011025	-7.8623	2.42e-13
engine_size	-0.015806	0.013255	-1.1925	0.23452
bore	-2.6998	1.3489	-2.0015	0.046711

Number of observations: 201, Error degrees of freedom: 197

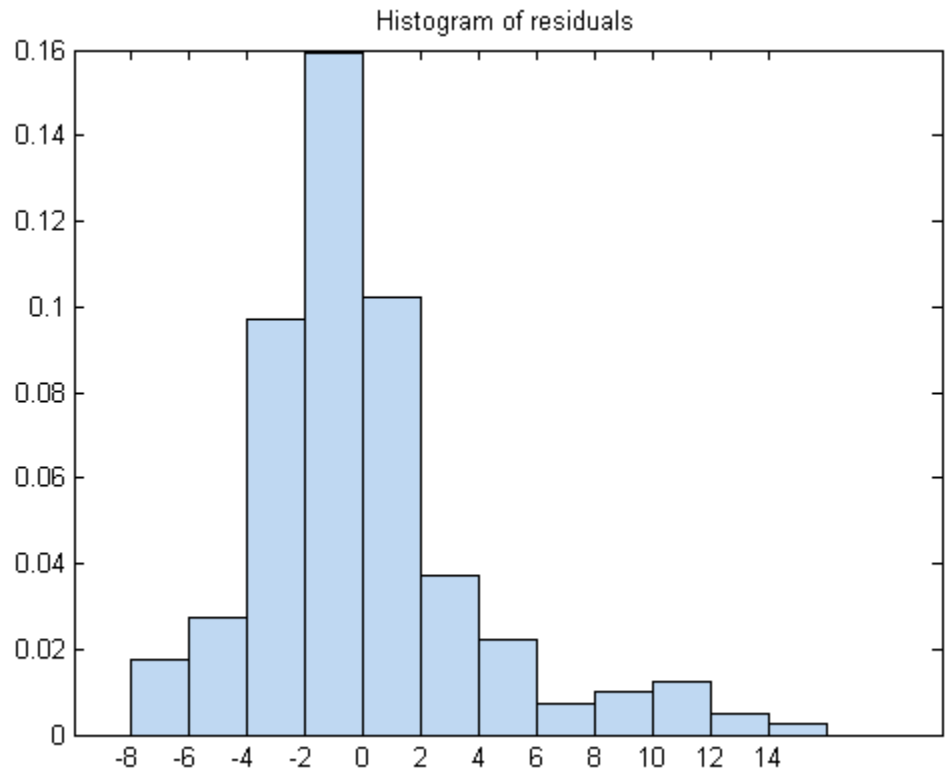
Root Mean Squared Error: 3.95

R-squared: 0.674, Adjusted R-Squared 0.669

F-statistic vs. constant model: 136, p-value = 1.14e-47

Plot the histogram of raw residuals.

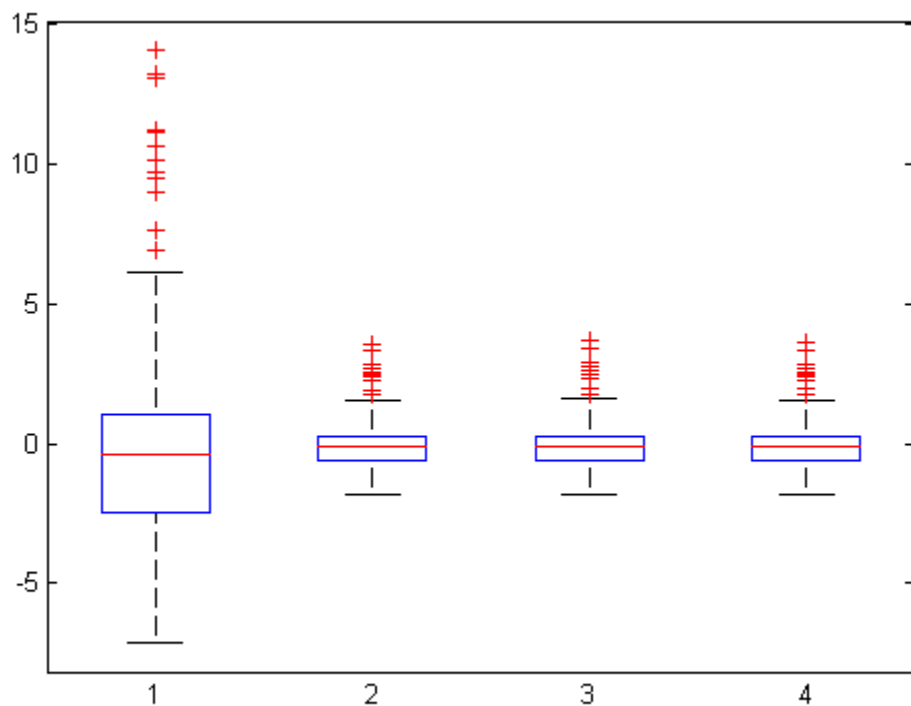
`plotResiduals(md1)`



The histogram shows that the residuals are slightly right skewed.

Plot the box plot of all four types of residuals.

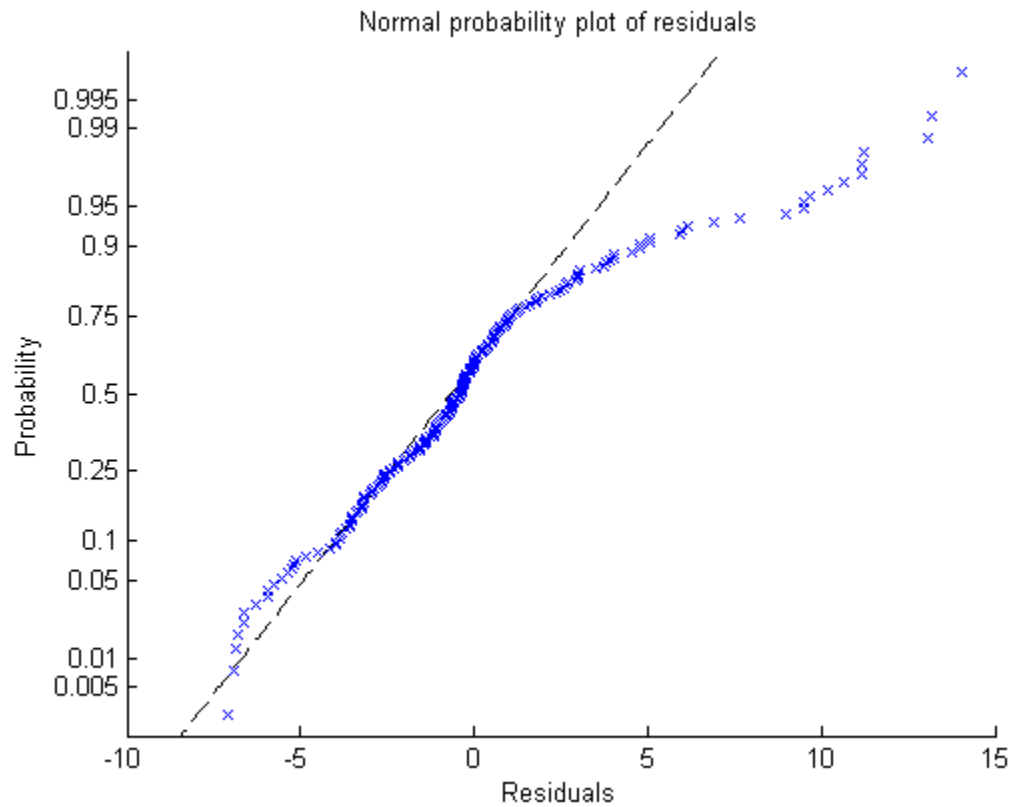
```
Res = double mdl.Residuals;
```



You can see the right-skewed structure of the residuals in the box plot as well.

Plot the normal probability plot of the raw residuals.

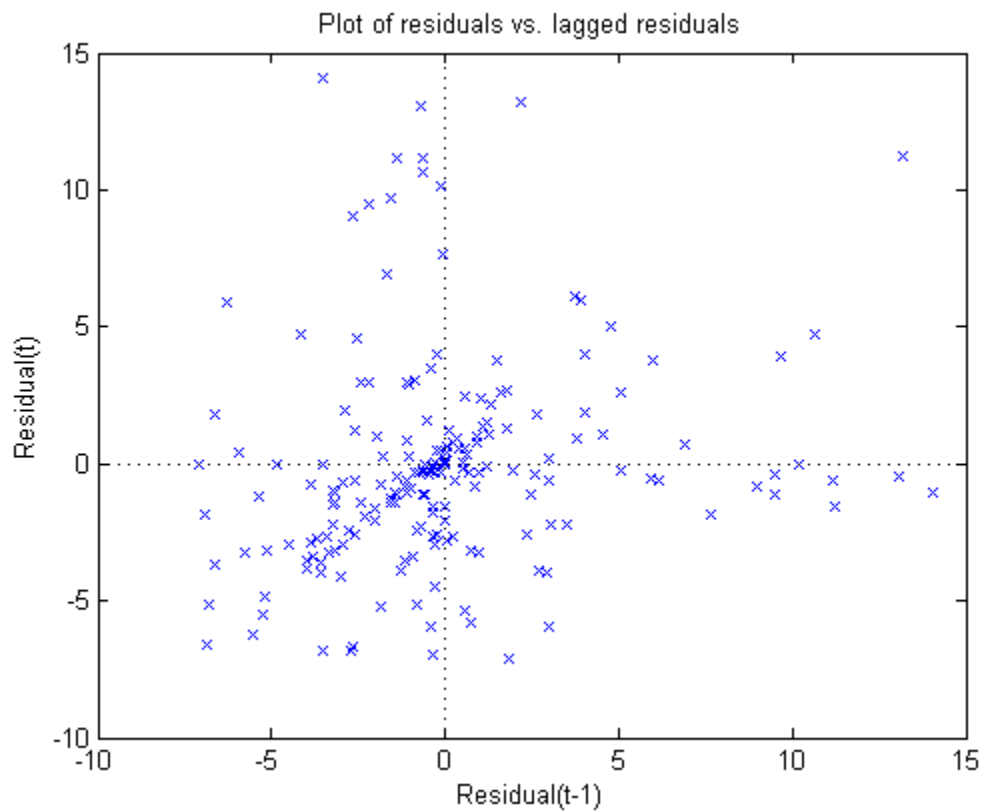
```
plotResiduals(mdl, 'probability')
boxplot(Res)
```



This normal probability plot also shows the deviation from normality and the skewness on the right tail of the distribution of residuals.

Plot the residuals versus lagged residuals.

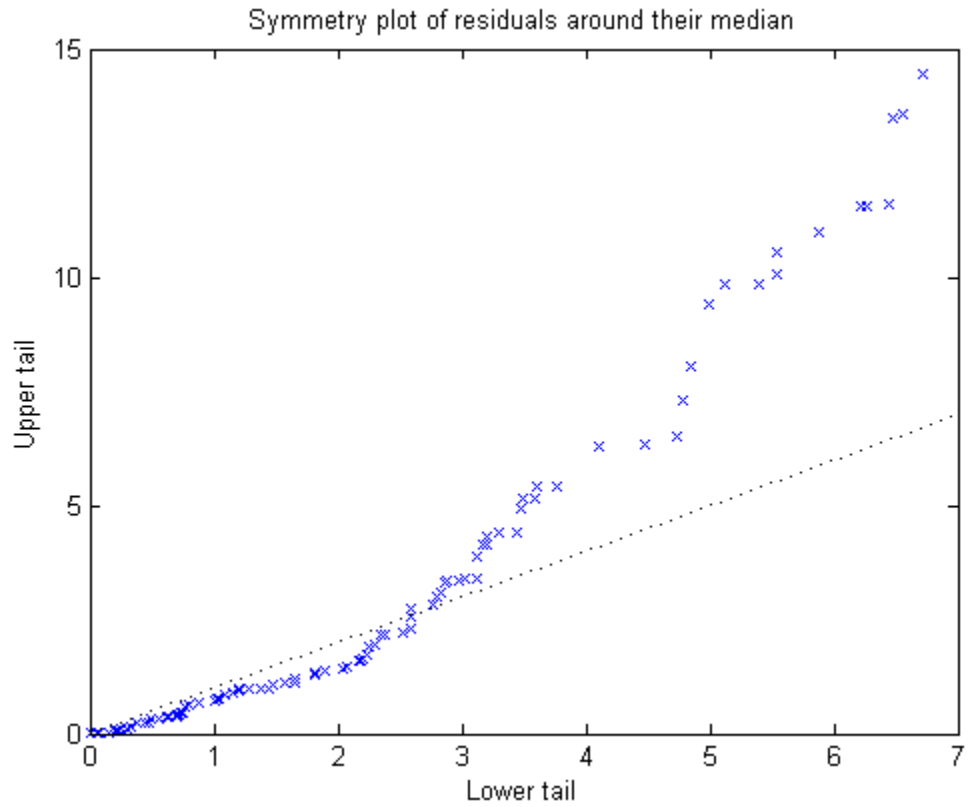
```
plotResiduals mdl, 'lagged'
```



This graph shows a trend, which indicates a possible correlation among the residuals. You can further check this using `dwtest(md1)`. Serial correlation among residuals usually means that the model can be improved.

Plot the symmetry plot of residuals.

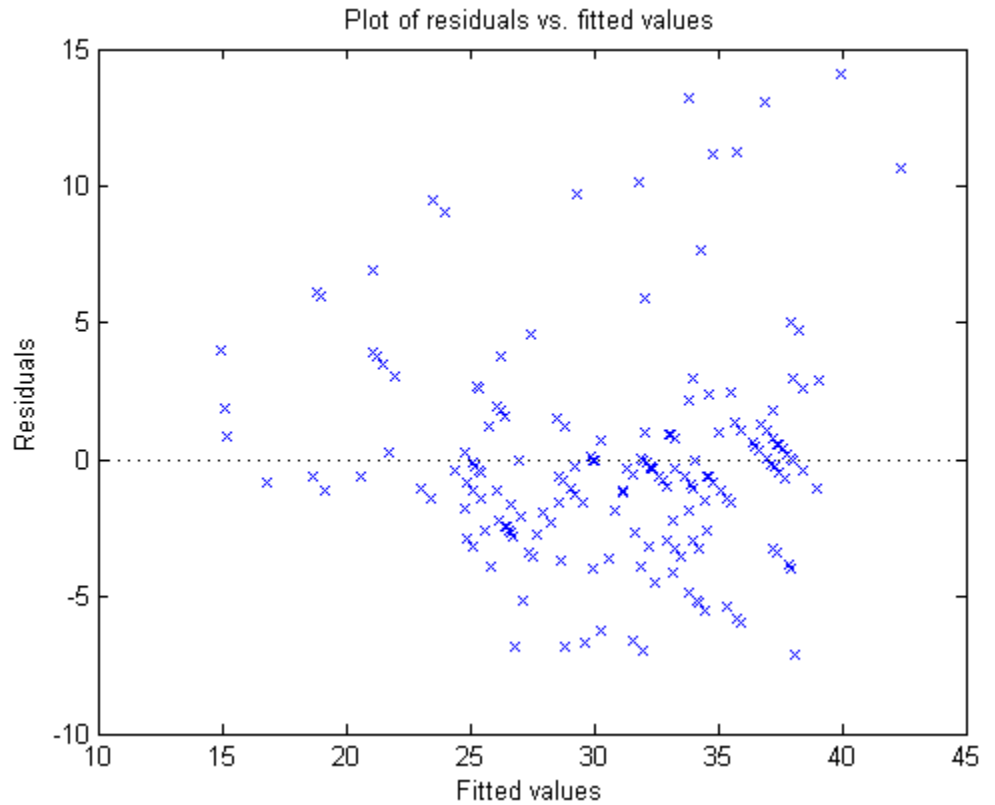
```
plotResiduals(md1, 'symmetry')
```



This plot also suggests that the residuals are not distributed equally around their median, as would be expected for normal distribution.

Plot the residuals versus the fitted values.

```
plotResiduals mdl, 'fitted'
```



The increase in the variance as the fitted values increase suggests possible heteroscedasticity.

[Return to Summary of Measures.](#)

t-statistic

Purpose

In linear regression, the t -statistic is useful for making inferences about the regression coefficients. The hypothesis test on coefficient i tests the null hypothesis that it is equal to zero – meaning the corresponding term is not

significant – versus the alternate hypothesis that the coefficient is different from zero.

Definition

For a hypotheses test on coefficient i , with

$$H_0 : \beta_i = 0$$

$$H_1 : \beta_i \neq 0,$$

the t -statistic is:

$$t = \frac{b_i}{SE(b_i)},$$

where $SE(b_i)$ is the standard error of the estimated coefficient b_i .

How To

After obtaining a fitted model, say, `mdl`, using `LinearModel.fit` or `LinearModel.stepwise`, you can:

- Find the coefficient estimates, the standard errors of the estimates (SE), and the t -statistic values of hypothesis tests for the corresponding coefficients (`tStat`) in the output display.
- Call for the display using

```
display(mdl)
```

Example

Load the sample data and fit the linear regression model.

```
load hald
mdl = LinearModel.fit(ingredients,heat)
```

```
mdl =
```

```
Linear regression model:
  y ~ 1 + x1 + x2 + x3 + x4
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	62.405	70.071	0.8906	0.39913
x1	1.5511	0.74477	2.0827	0.070822
x2	0.51017	0.72379	0.70486	0.5009
x3	0.10191	0.75471	0.13503	0.89592
x4	-0.14406	0.70905	-0.20317	0.84407

Number of observations: 13, Error degrees of freedom: 8

Root Mean Squared Error: 2.45

R-squared: 0.982, Adjusted R-Squared 0.974

F-statistic vs. constant model: 111, p-value = 4.76e-07

You can see that for each coefficient, $tStat = Estimate/SE$. The p -values for the hypotheses tests are in the $pValue$ column. Each t -statistic tests for the significance of each term given other terms in the model. According to these results, none of the coefficients seem significant at the 5% significance level, although the R-squared value for the model is really high at 0.97. This often indicates possible multicollinearity among the predictor variables.

Use stepwise regression to decide which variables to include in the model.

```
load hald
```

```
mdl = LinearModel.stepwise(ingredients,heat)
```

```
1. Adding x4, FStat = 22.7985, pValue = 0.000576232
```

```
2. Adding x1, FStat = 108.2239, pValue = 1.105281e-06
```

```
mdl =
```

Linear regression model:

$$y \sim 1 + x1 + x4$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	103.1	2.124	48.54	3.3243e-13
x1	1.44	0.13842	10.403	1.1053e-06

x4 -0.61395 0.048645 -12.621 1.8149e-07

Number of observations: 13, Error degrees of freedom: 10

Root Mean Squared Error: 2.73

R-squared: 0.972, Adjusted R-Squared 0.967

F-statistic vs. constant model: 177, p-value = 1.58e-08

In this example, `LinearModel.stepwise` starts with the constant model (default) and uses forward selection to incrementally add `x4` and `x1`. Each predictor variable in the final model is significant given the other one is in the model. The algorithm stops when adding none of the other predictor variables significantly improves in the model. For details on stepwise regression, see `LinearModel.stepwise`.

Return to Summary of Measures.

References

[1] Atkinson, A. T. *Plots, Transformations, and Regression. An Introduction to Graphical Methods of Diagnostic Regression Analysis*. New York: Oxford Statistical Science Series, Oxford University Press, 1987.

[2] Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. *Applied Linear Statistical Models*. IRWIN, The McGraw-Hill Companies, Inc., 1996.

[3] Belsley, D. A., E. Kuh, and R. E. Welsch. *Regression Diagnostics, Identifying Influential Data and Sources of Collinearity*. Wiley Series in Probability and Mathematical Statistics, John Wiley and Sons, Inc., 1980.

See Also

`LinearModel` | `LinearModel.fit` | `LinearModel.stepwise` | `plotDiagnostics` | `plotResiduals` | `anova` | `coefCI` | `coefTest` | `dwtest` |

Related Examples

- “Examine Quality and Adjust the Fitted Model” on page 9-17
- “Interpret Linear Regression Results” on page 9-60

Stepwise Regression

In this section...

“Stepwise Regression to Select Appropriate Models” on page 9-108

“Compare large and small stepwise models” on page 9-108

Stepwise Regression to Select Appropriate Models

`LinearModel.stepwise` creates a linear model and automatically adds to or trims the model. To create a small model, start from a constant model. To create a large model, start with a model containing many terms. A large model usually has lower error as measured by the fit to the original data, but might not have any advantage in predicting new data.

`LinearModel.stepwise` can use all the name-value options from `LinearModel.fit`, with additional options relating to the starting and bounding models. In particular:

- For a small model, start with the default lower bounding model: 'constant' (a model that has no predictor terms).
- The default upper bounding model has linear terms and interaction terms (products of pairs of predictors). For an upper bounding model that also includes squared terms, set the Upper name-value pair to 'quadratic'.

Compare large and small stepwise models

This example show how to compare the models that `LinearModel.stepwise` returns starting from a constant model and starting from a full interaction model.

Load the carbig data and create a dataset array from some of the data.

```
load carbig
ds = dataset(Acceleration,Displacement,Horsepower,Weight,MPG);
```

Create a mileage model stepwise starting from the constant model.

```
mdl1 = LinearModel.stepwise(ds,'constant','ResponseVar','MPG')
```

1. Adding Weight, FStat = 888.8507, pValue = 2.9728e-103
2. Adding Horsepower, FStat = 3.8217, pValue = 0.00049608
3. Adding Horsepower:Weight, FStat = 64.8709, pValue = 9.93362e-15

mdl1 =

Linear regression model:

MPG ~ 1 + Horsepower*Weight

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	63.558	2.3429	27.127	1.2343e-91
Horsepower	-0.25084	0.027279	-9.1952	2.3226e-18
Weight	-0.010772	0.00077381	-13.921	5.1372e-36
Horsepower:Weight	5.3554e-05	6.6491e-06	8.0542	9.9336e-15

Number of observations: 392, Error degrees of freedom: 388

Root Mean Squared Error: 3.93

R-squared: 0.748, Adjusted R-Squared 0.746

F-statistic vs. constant model: 385, p-value = 7.26e-116

Create a mileage model stepwise starting from the full interaction model.

```
mdl2 = LinearModel.stepwise(ds, 'interactions', 'ResponseVar', 'MPG')
```

1. Removing Acceleration:Displacement, FStat = 0.024186, pValue = 0.8765
2. Removing Displacement:Weight, FStat = 0.33103, pValue = 0.56539
3. Removing Acceleration:Horsepower, FStat = 1.7334, pValue = 0.18876
4. Removing Acceleration:Weight, FStat = 0.93269, pValue = 0.33477
5. Removing Horsepower:Weight, FStat = 0.64486, pValue = 0.42245

mdl2 =

Linear regression model:

MPG ~ 1 + Acceleration + Weight + Displacement*Horsepower

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	61.285	2.8052	21.847	1.8593e-69
Acceleration	-0.34401	0.11862	-2.9	0.0039445
Displacement	-0.081198	0.010071	-8.0623	9.5014e-15
Horsepower	-0.24313	0.026068	-9.3265	8.6556e-19
Weight	-0.0014367	0.00084041	-1.7095	0.088166
Displacement:Horsepower	0.00054236	5.7987e-05	9.3531	7.0527e-19

Number of observations: 392, Error degrees of freedom: 386

Root Mean Squared Error: 3.84

R-squared: 0.761, Adjusted R-Squared 0.758

F-statistic vs. constant model: 246, p-value = 1.32e-117

Notice that:

- `mdl1` has four coefficients (the Estimate column), and `mdl2` has six coefficients.
- The adjusted R-squared of `mdl1` is 0.746, which is slightly less (worse) than that of `mdl2`, 0.758.

Create a mileage model stepwise with a full quadratic model as the upper bound, starting from the full quadratic model:

```
mdl3 = LinearModel.stepwise(ds, 'quadratic', ...
    'ResponseVar', 'MPG', 'Upper', 'quadratic');
```

Compare the three model complexities by examining their formulas.

`mdl1.Formula`

```
ans =
MPG ~ 1 + Horsepower*Weight
```

`mdl2.Formula`

```
ans =
MPG ~ 1 + Acceleration + Weight + Displacement*Horsepower
```

`mdl3.Formula`

```
ans =  
MPG ~ 1 + Weight + Acceleration*Displacement  
      + Displacement*Horsepower + Acceleration^2
```

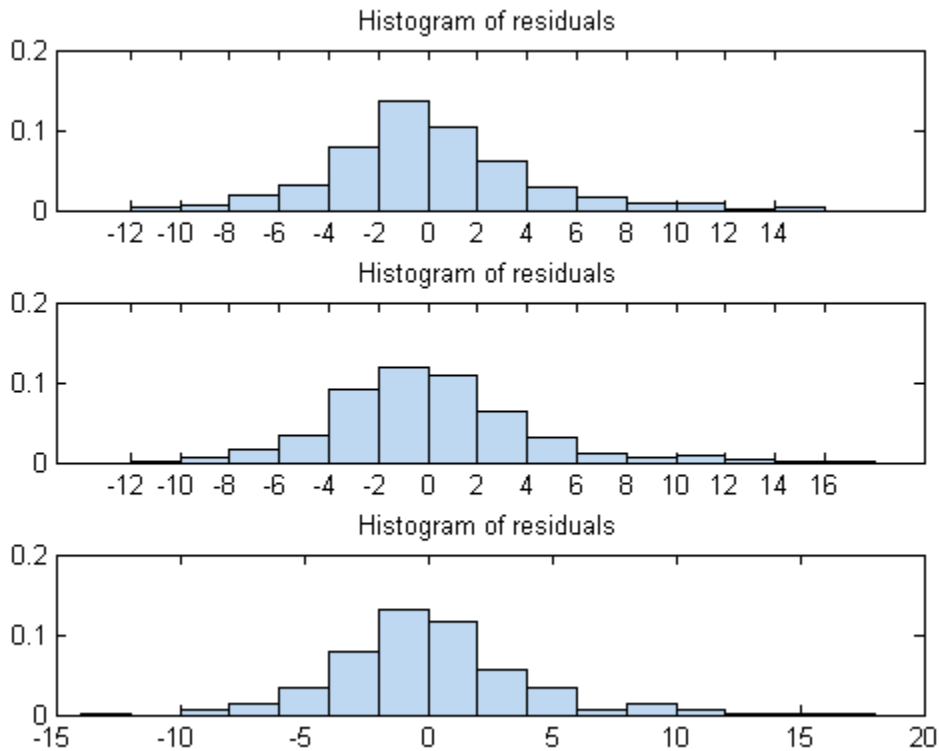
The adjusted R^2 values improve slightly as the models become more complex:

```
RSquared = [mdl1.Rsquared.Adjusted, ...  
            mdl2.Rsquared.Adjusted, mdl3.Rsquared.Adjusted]
```

```
RSquared =  
    0.7465    0.7580    0.7599
```

Compare residual plots of the three models.

```
subplot(3,1,1)  
plotResiduals(mdl1)  
subplot(3,1,2)  
plotResiduals(mdl2)  
subplot(3,1,3)  
plotResiduals(mdl3)
```



The models have similar residuals. It is not clear which fits the data better. Interestingly, the more complex models have larger maximum deviations of the residuals:

```

Range1 = [min(md11.Residuals.Raw),max(md11.Residuals.Raw)];
Range2 = [min(md12.Residuals.Raw),max(md12.Residuals.Raw)];
Range3 = [min(md13.Residuals.Raw),max(md13.Residuals.Raw)];
Ranges = [range1;range2;range3]

```

```

Ranges =
    -10.7725    14.7314
    -11.4407    16.7562
    -12.2723    16.7927

```


Robust Regression — Reduce Outlier Effects

In this section...

“What Is Robust Regression?” on page 9-113

“Robust Regression versus Standard Least-Squares Fit” on page 9-113

What Is Robust Regression?

The models described in “What Is a Linear Regression Model?” on page 9-7 are based on certain assumptions, such as a normal distribution of errors in the observed responses. If the distribution of errors is asymmetric or prone to outliers, model assumptions are invalidated, and parameter estimates, confidence intervals, and other computed statistics become unreliable. Use `LinearModel.fit` with the `RobustOpts` name-value pair to create a model that is not much affected by outliers. The robust fitting method is less sensitive than ordinary least squares to large changes in small parts of the data.

Robust regression works by assigning a weight to each data point. Weighting is done automatically and iteratively using a process called *iteratively reweighted least squares*. In the first iteration, each point is assigned equal weight and model coefficients are estimated using ordinary least squares. At subsequent iterations, weights are recomputed so that points farther from model predictions in the previous iteration are given lower weight. Model coefficients are then recomputed using weighted least squares. The process continues until the values of the coefficient estimates converge within a specified tolerance.

Robust Regression versus Standard Least-Squares Fit

This example shows how to use robust regression. It compares the results of a robust fit to a standard least-squares fit.

Step 1. Prepare data.

Load the moore data. The data is in the first five columns, and the response in the sixth.

```
load moore
```

```
X = [moore(:,1:5)];
y = moore(:,6);
```

Step 2. Fit robust and nonrobust models.

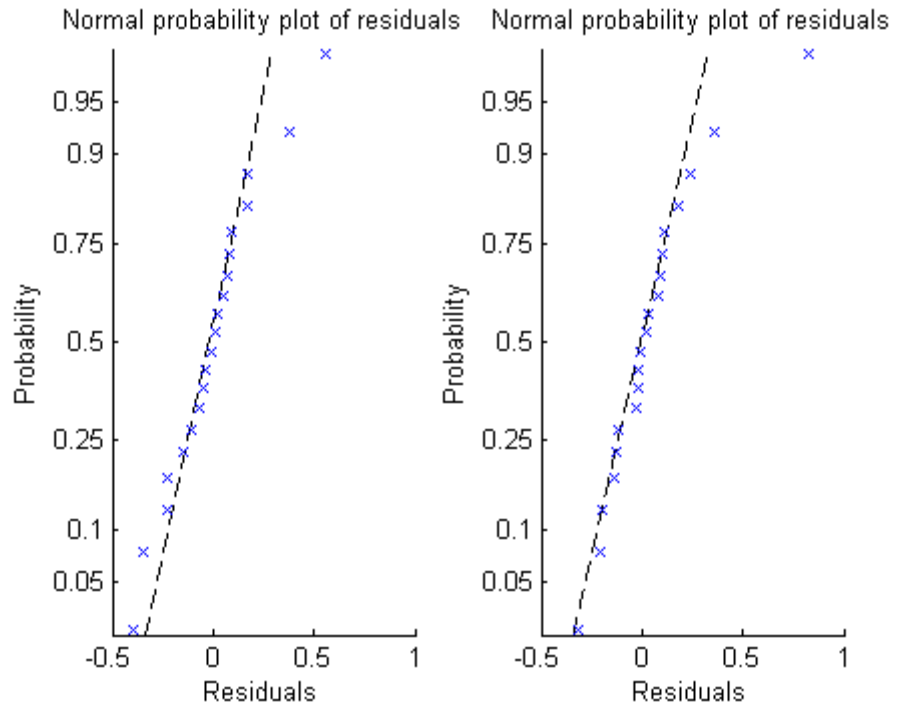
Fit two linear models to the data, one using robust fitting, one not.

```
mdl = LinearModel.fit(X,y); % not robust
mdlr = LinearModel.fit(X,y,'RobustOpts','on');
```

Step 3. Examine model residuals.

Examine the residuals of the two models.

```
subplot(1,2,1);plotResiduals(mdl,'probability')
subplot(1,2,2);plotResiduals(mdlr,'probability')
```



The residuals from the robust fit (right half of the plot) are nearly all closer to the straight line, except for the one obvious outlier.

4. Remove the outlier from the standard model

Find the index of the outlier. Examine the weight of the outlier in the robust fit.

```
[~,outlier] = max mdlr.Residuals.Raw);  
mdlr.Robust.Weights(outlier)
```

```
ans =
```

```
0.0246
```

This weight is much less than a typical weight of an observation:

```
median(mdlr.Robust.Weights)
```

```
ans =
```

```
0.9718
```

Ridge Regression

In this section...

“Introduction to Ridge Regression” on page 9-116

“Ridge Regression” on page 9-116

Introduction to Ridge Regression

Coefficient estimates for the models described in “Linear Regression” on page 9-7 rely on the independence of the model terms. When terms are correlated and the columns of the design matrix X have an approximate linear dependence, the matrix $(X^T X)^{-1}$ becomes close to singular. As a result, the least-squares estimate

$$\hat{\beta} = (X^T X)^{-1} X^T y$$

becomes highly sensitive to random errors in the observed response y , producing a large variance. This situation of *multicollinearity* can arise, for example, when data are collected without an experimental design.

Ridge regression addresses the problem by estimating regression coefficients using

$$\hat{\beta} = (X^T X + kI)^{-1} X^T y$$

where k is the *ridge parameter* and I is the identity matrix. Small positive values of k improve the conditioning of the problem and reduce the variance of the estimates. While biased, the reduced variance of ridge estimates often result in a smaller mean square error when compared to least-squares estimates.

The Statistics Toolbox function `ridge` carries out ridge regression.

Ridge Regression

For example, load the data in `acetylene.mat`, with observations of the predictor variables `x1`, `x2`, `x3`, and the response variable `y`:

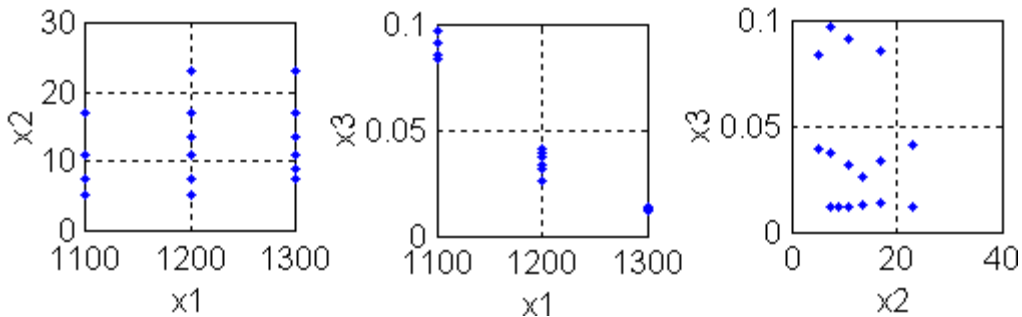
```
load acetylene
```

Plot the predictor variables against each other:

```
subplot(1,3,1)
plot(x1,x2,'. ')
xlabel('x1'); ylabel('x2'); grid on; axis square
```

```
subplot(1,3,2)
plot(x1,x3,'. ')
xlabel('x1'); ylabel('x3'); grid on; axis square
```

```
subplot(1,3,3)
plot(x2,x3,'. ')
xlabel('x2'); ylabel('x3'); grid on; axis square
```



Note the correlation between x_1 and the other two predictor variables.

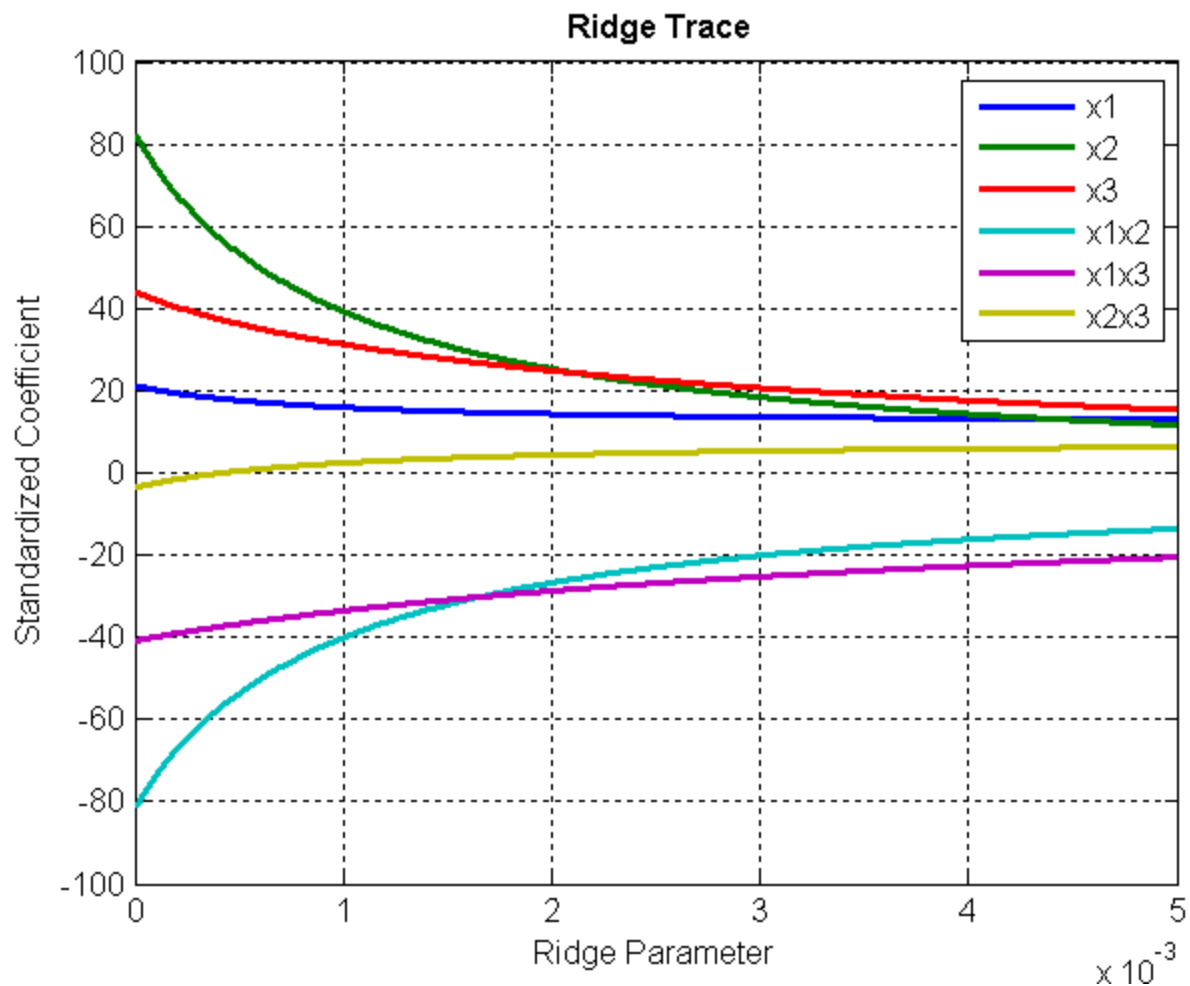
Use `ridge` and `x2fx` to compute coefficient estimates for a multilinear model with interaction terms, for a range of ridge parameters:

```
X = [x1 x2 x3];
D = x2fx(X,'interaction');
D(:,1) = []; % No constant term
k = 0:1e-5:5e-3;
betahat = ridge(y,D,k);
```

Plot the ridge trace:

```
figure
```

```
plot(k,betahat,'LineWidth',2)
ylim([-100 100])
grid on
xlabel('Ridge Parameter')
ylabel('Standardized Coefficient')
title('\bf Ridge Trace')
legend('x1','x2','x3','x1x2','x1x3','x2x3')
```



The estimates stabilize to the right of the plot. Note that the coefficient of the x_2x_3 interaction term changes sign at a value of the ridge parameter $\approx 5 \times 10^{-4}$.

Lasso and Elastic Net

In this section...

“What Are Lasso and Elastic Net?” on page 9-120

“Lasso Regularization” on page 9-120

“Lasso and Elastic Net with Cross Validation” on page 9-123

“Wide Data via Lasso and Parallel Computing” on page 9-126

“Lasso and Elastic Net Details” on page 9-131

“References” on page 9-133

What Are Lasso and Elastic Net?

Lasso is a regularization technique. Use `lasso` to:

- Reduce the number of predictors in a regression model.
- Identify important predictors.
- Select among redundant predictors.
- Produce shrinkage estimates with potentially lower predictive errors than ordinary least squares.

Elastic net is a related technique. Use `elastic net` when you have several highly correlated variables. `lasso` provides elastic net regularization when you set the `Alpha` name-value pair to a number strictly between 0 and 1.

See “Lasso and Elastic Net Details” on page 9-131.

For lasso regularization of regression ensembles, see `regularize`.

Lasso Regularization

To see how `lasso` identifies and discards unnecessary predictors:

- 1 Generate 200 samples of five-dimensional artificial data X from exponential distributions with various means:


```

rng(3,'twister') % for reproducibility
X = zeros(200,5);
for ii = 1:5
    X(:,ii) = exprnd(ii,200,1);
end

```

- 2** Generate response data $Y = X*r + \text{eps}$ where r has just two nonzero components, and the noise eps is normal with standard deviation 0.1:

```

r = [0;2;0;-3;0];
Y = X*r + randn(200,1)*.1;

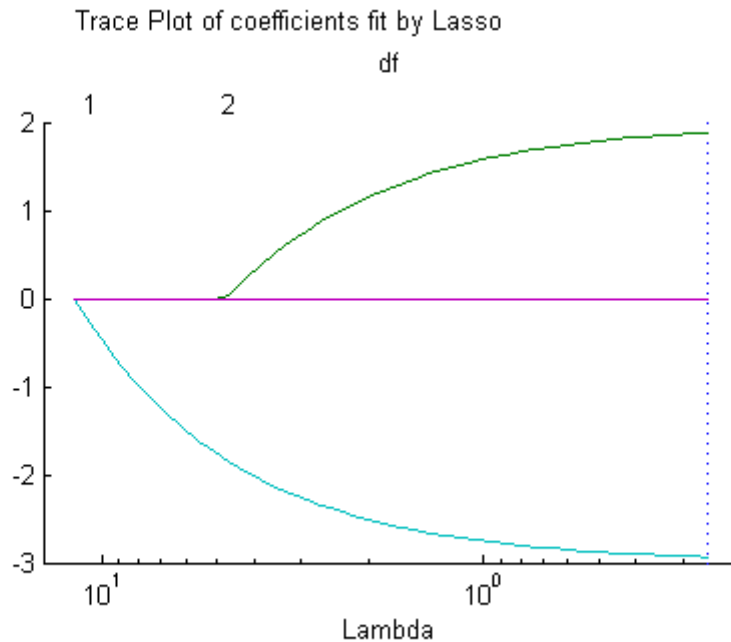
```

- 3** Fit a cross-validated sequence of models with `lasso`, and plot the result:

```

[b fitinfo] = lasso(X,Y,'CV',10);
lassoPlot(b,fitinfo,'PlotType','Lambda','XScale','log');

```



The plot shows the nonzero coefficients in the regression for various values of the Lambda regularization parameter. Larger values of Lambda appear on the left side of the graph, meaning more regularization, resulting in fewer nonzero regression coefficients.

The dashed vertical lines represent the Lambda value with minimal mean squared error (on the right), and the Lambda value with minimal mean squared error plus one standard deviation. This latter value is a recommended setting for Lambda. These lines appear only when you perform cross validation. Cross validate by setting the 'CV' name-value pair. This example uses 10-fold cross validation.

The upper part of the plot shows the degrees of freedom (df), meaning the number of nonzero coefficients in the regression, as a function of Lambda. On the left, the large value of Lambda causes all but one coefficient to be 0. On the right all five coefficients are nonzero, though the plot shows only two clearly. The other three coefficients are so small that you cannot visually distinguish them from 0.

For small values of Lambda (toward the right in the plot), the coefficient values are close to the least-squares estimate. See step 5 on page 9-123.

- 4 Find the Lambda value of the minimal cross-validated mean squared error plus one standard deviation. Examine the MSE and coefficients of the fit at that Lambda:

```
lam = fitinfo.Index1SE;  
fitinfo.MSE(lam)
```

```
ans =  
    0.1398
```

```
b(:,lam)
```

```
ans =  
     0  
    1.8855  
     0  
   -2.9367  
     0
```

lasso did a good job finding the coefficient vector r .

- 5** For comparison, find the least-squares estimate of r :

```
rhat = X\Y
```

```
rhat =
```

```
-0.0038
 1.9952
 0.0014
-2.9993
 0.0031
```

The estimate $b(:, \lambda)$ has slightly more mean squared error than the mean squared error of $rhat$:

```
res = X*rhat - Y; % calculate residuals
MSEmin = res'*res/200 % b(:,lam) value is 0.1398
```

```
MSEmin =
 0.0088
```

But $b(:, \lambda)$ has only two nonzero components, and therefore can provide better predictive estimates on new data.

Lasso and Elastic Net with Cross Validation

Consider predicting the mileage (MPG) of a car based on its weight, displacement, horsepower, and acceleration. The `carbig` data contains these measurements. The data seem likely to be correlated, making elastic net an attractive choice.

- 1** Load the data:

```
load carbig
```

- 2** Extract the continuous (noncategorical) predictors (lasso does not handle categorical predictors):

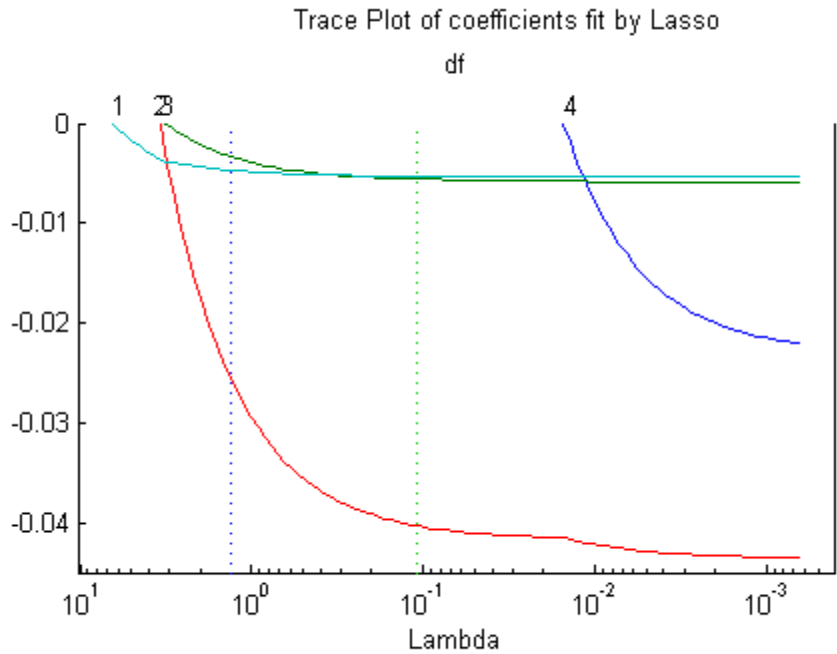
```
X = [Acceleration Displacement Horsepower Weight];
```

3 Perform a lasso fit with 10-fold cross validation:

```
[b fitinfo] = lasso(X,MPG,'CV',10);
```

4 Plot the result:

```
lassoPlot(b,fitinfo,'PlotType','Lambda','XScale','log');
```



5 Calculate the correlation of the predictors:

```
% Eliminate NaNs so corr runs
nonan = ~any(isnan([X MPG]),2);
Xnonan = X(nonan,:);
MPGnonan = MPG(nonan,:);
corr(Xnonan)

ans =
```

```

1.0000 -0.5438 -0.6892 -0.4168
-0.5438 1.0000 0.8973 0.9330
-0.6892 0.8973 1.0000 0.8645
-0.4168 0.9330 0.8645 1.0000

```

- 6** Because some predictors are highly correlated, perform elastic net fitting. Use Alpha = 0.5:

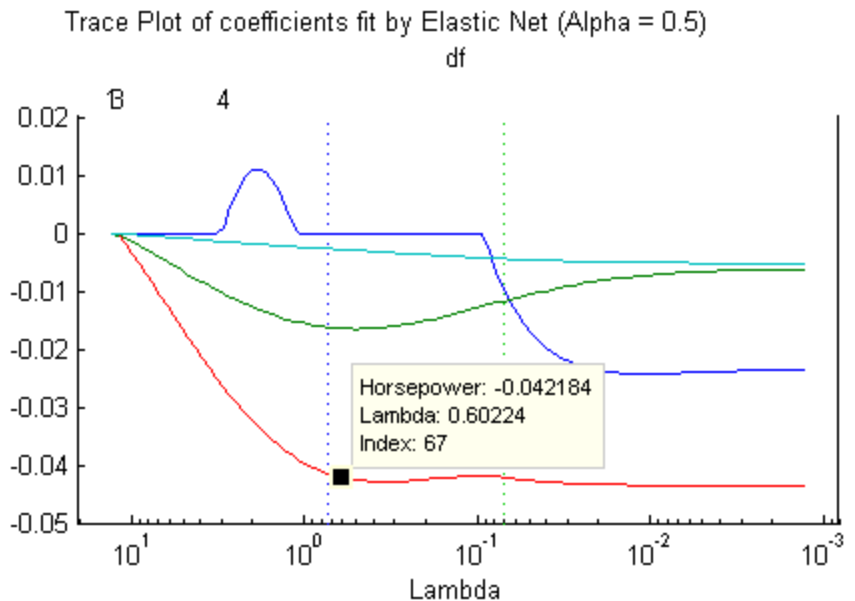
```
[ba fitinfoa] = lasso(X,MPG,'CV',10,'Alpha',.5);
```

- 7** Plot the result. Name each predictor so you can tell which curve is which:

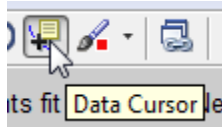
```

pnames = {'Acceleration','Displacement',...
          'Horsepower','Weight'};
lassoPlot(ba,fitinfoa,'PlotType','Lambda',...
          'XScale','log','PredictorNames',pnames);

```



When you activate the data cursor



and click the plot, you see the name of the predictor, the coefficient, the value of Lambda , and the index of that point, meaning the column in \mathbf{b} associated with that fit.

Here, the elastic net and lasso results are not very similar. Also, the elastic net plot reflects a notable qualitative property of the elastic net technique. The elastic net retains three nonzero coefficients as Lambda increases (toward the left of the plot), and these three coefficients reach 0 at about the same Lambda value. In contrast, the lasso plot shows two of the three coefficients becoming 0 at the same value of Lambda , while another coefficient remains nonzero for higher values of Lambda .

This behavior exemplifies a general pattern. In general, elastic net tends to retain or drop groups of highly correlated predictors as Lambda increases. In contrast, lasso tends to drop smaller groups, or even individual predictors.

Wide Data via Lasso and Parallel Computing

Lasso and elastic net are especially well suited to *wide* data, meaning data with more predictors than observations. Obviously, there are redundant predictors in this type of data. Use lasso along with cross validation to identify important predictors.

Cross validation can be slow. If you have a Parallel Computing Toolbox license, speed the computation using parallel computing.

1 Load the spectra data:

```
load spectra
Description

Description =

== Spectral and octane data of gasoline ==
```

NIR spectra and octane numbers of 60 gasoline samples

NIR: NIR spectra, measured in 2 nm intervals from 900 nm to 1700 nm

octane: octane numbers

spectra: a dataset array containing variables for NIR and octane

Reference:

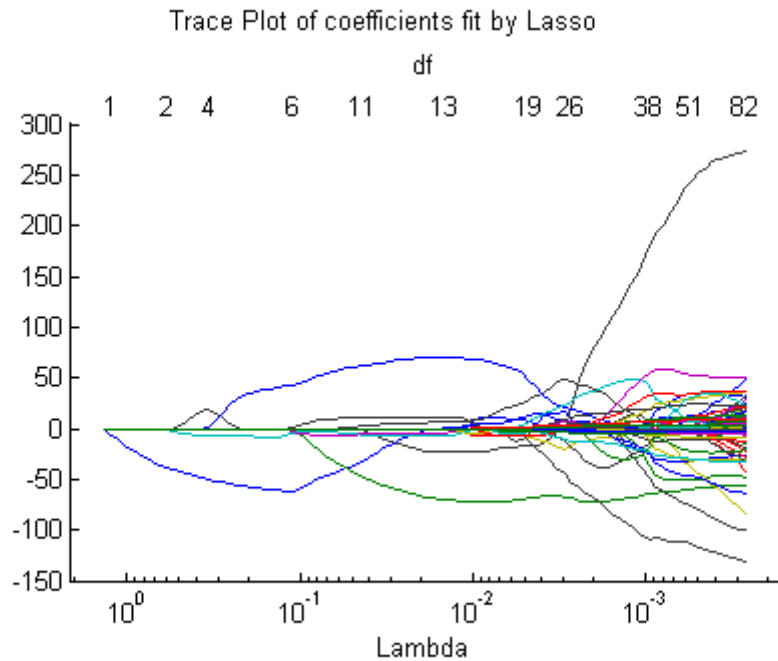
Kalivas, John H., "Two Data Sets of Near Infrared Spectra," *Chemometrics and Intelligent Laboratory Systems*, v.37 (1997) pp.255-259

2 Compute the default lasso fit:

```
[b fitinfo] = lasso(NIR,octane);
```

3 Plot the number of predictors in the fitted lasso regularization as a function of Lambda, using a logarithmic x -axis:

```
lassoPlot(b,fitinfo,'PlotType','Lambda','XScale','log');
```



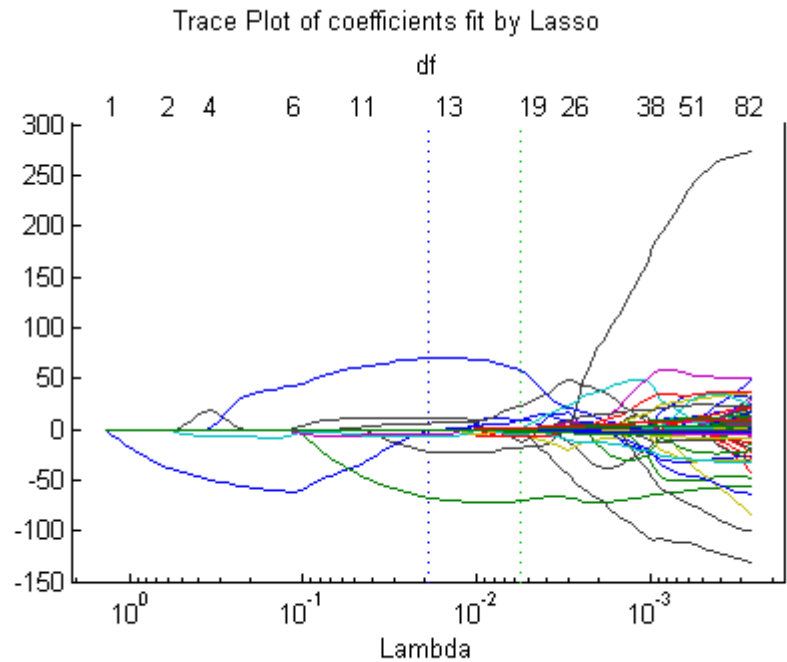
- 4 It is difficult to tell which value of Lambda is appropriate. To determine a good value, try fitting with cross validation:

```
tic
[b fitinfo] = lasso(NIR,octane,'CV',10);
% A time-consuming operation
toc
```

Elapsed time is 226.876926 seconds.

- 5 Plot the result:

```
lassoPlot(b,fitinfo,'PlotType','Lambda','XScale','log');
```

You can see the suggested value of Lambda is over $1e-2$, and the Lambda with minimal MSE is under $1e-2$. These values are in the `fitinfo` structure:

```
fitinfo.LambdaMinMSE
```

```
ans =  
    0.0057
```

```
fitinfo.Lambda1SE
```

```
ans =  
    0.0190
```

- 6 Examine the quality of the fit for the suggested value of Lambda:

```
lambdaindex = fitinfo.Index1SE;  
fitinfo.MSE(lambdaindex)
```

```
ans =
    0.0532
```

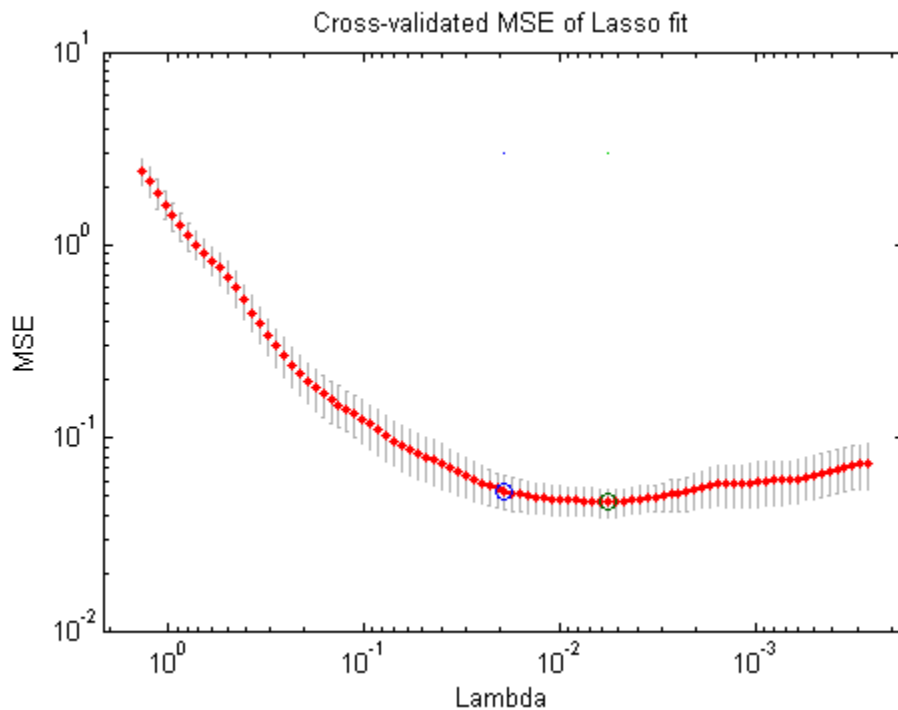
```
fitinfo.DF(lambdaindex)
```

```
ans =
    11
```

The fit uses just 11 of the 401 predictors, and achieves a cross-validated MSE of 0.0532.

7 Examine the plot of cross-validated MSE:

```
lassoPlot(b,fitinfo,'PlotType','CV');
% Use a log scale for MSE to see small MSE values better
set(gca,'YScale','log');
```



As `Lambda` increases (toward the left), MSE increases rapidly. The coefficients are reduced too much and they do not adequately fit the responses.

As `Lambda` decreases, the models are larger (have more nonzero coefficients). The increasing MSE suggests that the models are overfitted.

The default set of `Lambda` values does not include values small enough to include all predictors. In this case, there does not appear to be a reason to look at smaller values. However, if you want smaller values than the default, use the `LambdaRatio` parameter, or supply a sequence of `Lambda` values using the `Lambda` parameter. For details, see the `lasso` reference page.

- 8 To compute the cross-validated lasso estimate faster, use parallel computing (available with a Parallel Computing Toolbox license):

```
matlabpool open
Starting matlabpool using the 'local' configuration ...
    connected to 4 labs.

opts = statset('UseParallel','always');
tic;
[b fitinfo] = lasso(NIR,octane,'CV',10,'Options',opts);
toc
```

Elapsed time is 107.539719 seconds.

Computing in parallel is more than twice as fast on this problem using a quad-core processor.

Lasso and Elastic Net Details

Overview of Lasso and Elastic Net

Lasso is a regularization technique for performing linear regression. Lasso includes a penalty term that constrains the size of the estimated coefficients. Therefore, it resembles ridge regression. Lasso is a *shrinkage estimator*: it generates coefficient estimates that are biased to be small. Nevertheless, a lasso estimator can have smaller mean squared error than an ordinary least-squares estimator when you apply it to new data.

Unlike ridge regression, as the penalty term increases, lasso sets more coefficients to zero. This means that the lasso estimator is a smaller model, with fewer predictors. As such, lasso is an alternative to stepwise regression and other model selection and dimensionality reduction techniques.

Elastic net is a related technique. Elastic net is a hybrid of ridge regression and lasso regularization. Like lasso, elastic net can generate reduced models by generating zero-valued coefficients. Empirical studies have suggested that the elastic net technique can outperform lasso on data with highly correlated predictors.

Definition of Lasso

The *lasso* technique solves this regularization problem. For a given value of λ , a nonnegative parameter, lasso solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{2N} \sum_{i=1}^N (y_i - \beta_0 - x_i^T \beta)^2 + \lambda \sum_{j=1}^p |\beta_j| \right),$$

where

- N is the number of observations.
- y_i is the response at observation i .
- x_i is data, a vector of p values at observation i .
- λ is a positive regularization parameter corresponding to one value of Λ .
- The parameters β_0 and β are scalar and p -vector respectively.

As λ increases, the number of nonzero components of β decreases.

The lasso problem involves the L^1 norm of β , as contrasted with the elastic net algorithm.

Definition of Elastic Net

The *elastic net* technique solves this regularization problem. For an α strictly between 0 and 1, and a nonnegative λ , elastic net solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{2N} \sum_{i=1}^N (y_i - \beta_0 - x_i^T \beta)^2 + \lambda P_\alpha(\beta) \right),$$

where

$$P_\alpha(\beta) = \frac{(1-\alpha)}{2} \|\beta\|_2^2 + \alpha \|\beta\|_1 = \sum_{j=1}^p \left(\frac{(1-\alpha)}{2} \beta_j^2 + \alpha |\beta_j| \right).$$

Elastic net is the same as lasso when $\alpha = 1$. As α shrinks toward 0, elastic net approaches ridge regression. For other values of α , the penalty term $P_\alpha(\beta)$ interpolates between the L^1 norm of β and the squared L^2 norm of β .

References

- [1] Tibshirani, R. *Regression shrinkage and selection via the lasso*. Journal of the Royal Statistical Society, Series B, Vol 58, No. 1, pp. 267–288, 1996.
- [2] Zou, H. and T. Hastie. *Regularization and variable selection via the elastic net*. Journal of the Royal Statistical Society, Series B, Vol. 67, No. 2, pp. 301–320, 2005.
- [3] Friedman, J., R. Tibshirani, and T. Hastie. *Regularization paths for generalized linear models via coordinate descent*. Journal of Statistical Software, Vol 33, No. 1, 2010. <http://www.jstatsoft.org/v33/i01>
- [4] Hastie, T., R. Tibshirani, and J. Friedman. *The Elements of Statistical Learning*, 2nd edition. Springer, New York, 2008.

Partial Least Squares

In this section...
“Introduction to Partial Least Squares” on page 9-134
“Partial Least Squares” on page 9-135

Introduction to Partial Least Squares

Partial least-squares (PLS) regression is a technique used with data that contain correlated predictor variables. This technique constructs new predictor variables, known as *components*, as linear combinations of the original predictor variables. PLS constructs these components while considering the observed response values, leading to a parsimonious model with reliable predictive power.

The technique is something of a cross between multiple linear regression and principal component analysis:

- Multiple linear regression finds a combination of the predictors that best fit a response.
- Principal component analysis finds combinations of the predictors with large variance, reducing correlations. The technique makes no use of response values.
- PLS finds combinations of the predictors that have a large covariance with the response values.

PLS therefore combines information about the variances of both the predictors and the responses, while also considering the correlations among them.

PLS shares characteristics with other regression and feature transformation techniques. It is similar to ridge regression in that it is used in situations with correlated predictors. It is similar to stepwise regression (or more general feature selection techniques) in that it can be used to select a smaller set of model terms. PLS differs from these methods, however, by transforming the original predictor space into the new component space.

The Statistics Toolbox function `pplsregress` carries out PLS regression.

Partial Least Squares

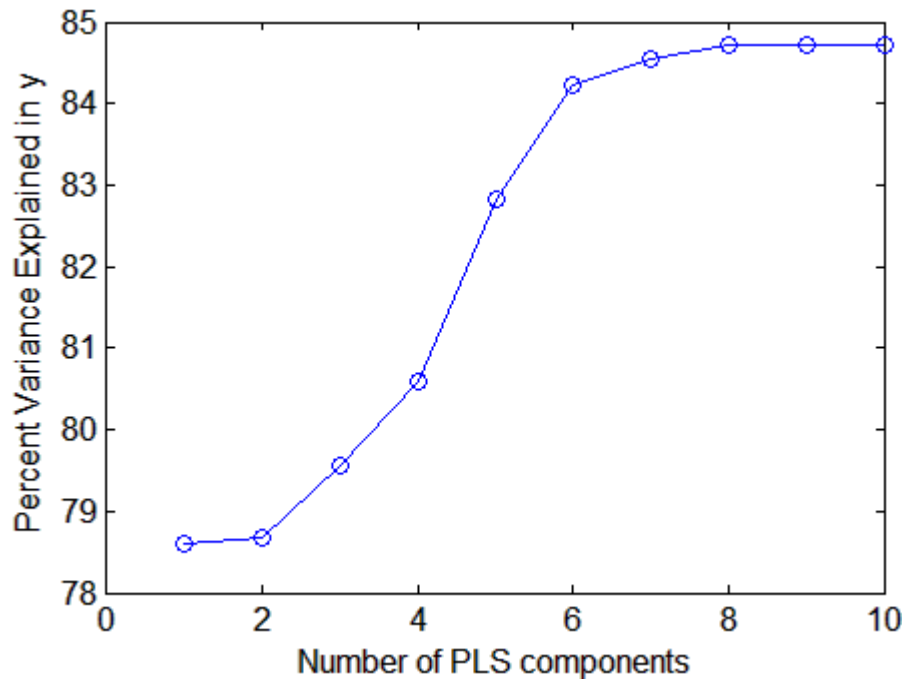
For example, consider the data on biochemical oxygen demand in `moore.mat`, padded with noisy versions of the predictors to introduce correlations:

```
load moore
y = moore(:,6);           % Response
X0 = moore(:,1:5);       % Original predictors
X1 = X0+10*randn(size(X0)); % Correlated predictors
X = [X0,X1];
```

Use `plsregress` to perform PLS regression with the same number of components as predictors, then plot the percentage variance explained in the response as a function of the number of components:

```
[XL,y1,XS,YS,beta,PCTVAR] = plsregress(X,y,10);

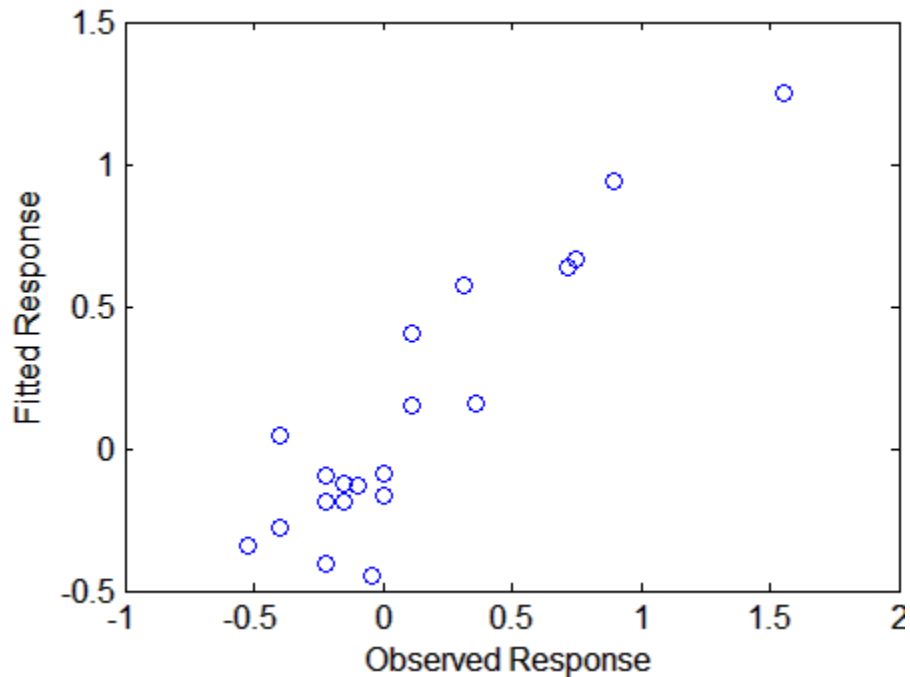
plot(1:10,cumsum(100*PCTVAR(2,:)),'-bo');
xlabel('Number of PLS components');
ylabel('Percent Variance Explained in y');
```



Choosing the number of components in a PLS model is a critical step. The plot gives a rough indication, showing nearly 80% of the variance in y explained by the first component, with as many as five additional components making significant contributions.

The following computes the six-component model:

```
[XL,y1,XS,YS,beta,PCTVAR,MSE,stats] = plsregress(X,y,6);  
yfit = [ones(size(X,1),1) X]*beta;  
  
plot(y,yfit,'o')
```

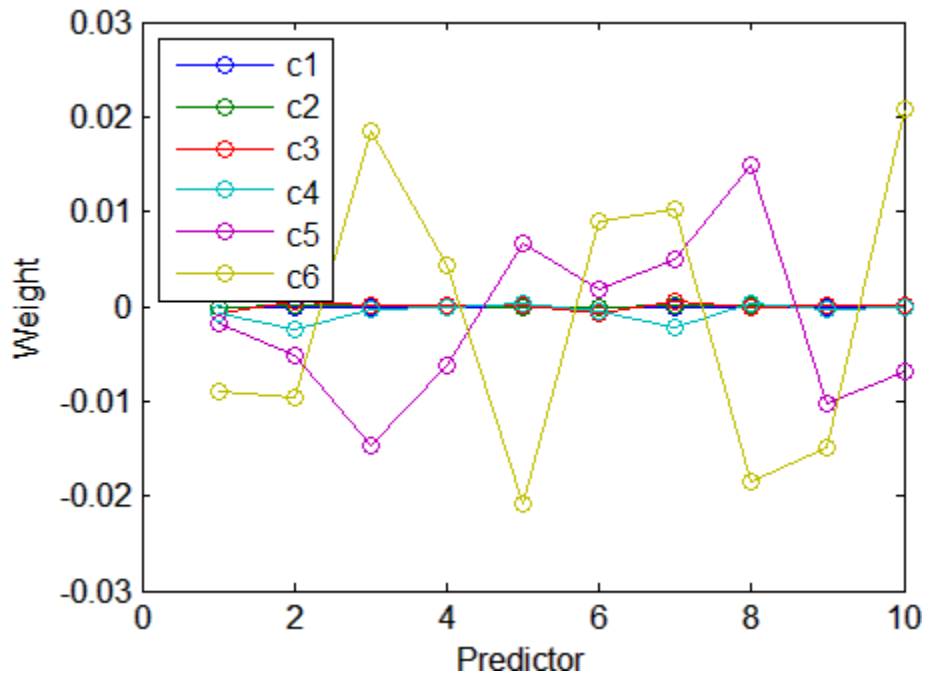



The scatter shows a reasonable correlation between fitted and observed responses, and this is confirmed by the R^2 statistic:

```
TSS = sum((y-mean(y)).^2);
RSS = sum((y-yfit).^2);
Rsquared = 1 - RSS/TSS
Rsquared =
    0.8421
```

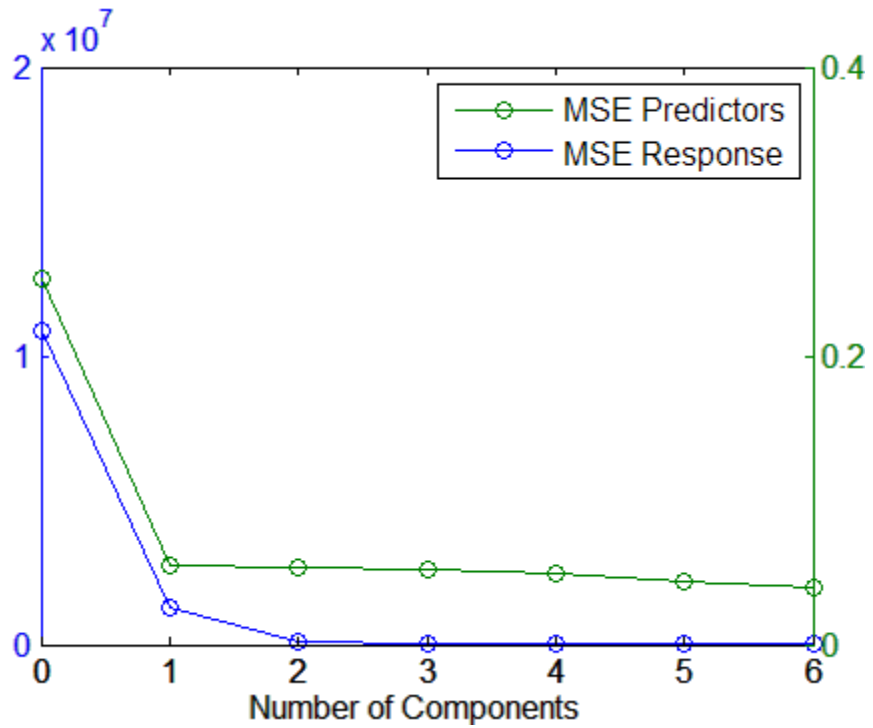
A plot of the weights of the ten predictors in each of the six components shows that two of the components (the last two computed) explain the majority of the variance in X :

```
plot(1:10,stats.W,'o-');
legend({'c1','c2','c3','c4','c5','c6'},'Location','NW')
xlabel('Predictor');
ylabel('Weight');
```



A plot of the mean-squared errors suggests that as few as two components may provide an adequate model:

```
[axes,h1,h2] = plotyy(0:6,MSE(1,:),0:6,MSE(2,:));
set(h1,'Marker','o')
set(h2,'Marker','o')
legend('MSE Predictors','MSE Response')
xlabel('Number of Components')
```



The calculation of mean-squared errors by `plsregress` is controlled by optional parameter name/value pairs specifying cross-validation type and the number of Monte Carlo repetitions.

Multivariate Regression

Whether or not the predictor \mathbf{x} is a vector of predictor variables, *multivariate regression* refers to the case where the response $\mathbf{y} = (y_1, \dots, y_M)$ is a vector of M response variables.

The Statistics Toolbox functions `mvregress` and `mvregresslike` are used for multivariate regression analysis.

Generalized Linear Models

In this section...

“What Are Generalized Linear Models?” on page 9-141

“Prepare Data” on page 9-142

“Choose Generalized Linear Model and Link Function” on page 9-144

“Choose Fitting Method and Model” on page 9-148

“Fit Model to Data” on page 9-153

“Examine Quality and Adjust the Fitted Model” on page 9-154

“Predict or Simulate Responses to New Data” on page 9-166

“Share Fitted Models” on page 9-169

“Generalized Linear Model Workflow” on page 9-171

What Are Generalized Linear Models?

Linear regression models describe a linear relationship between a response and one or more predictive terms. Many times, however, a nonlinear relationship exists. “Nonlinear Regression” on page 9-196 describes general nonlinear models. A special class of nonlinear models, called *generalized linear models*, uses linear methods.

Recall that linear models have these characteristics:

- At each set of values for the predictors, the response has a normal distribution with mean μ .
- A coefficient vector b defines a linear combination Xb of the predictors X .
- The model is $\mu = Xb$.

In generalized linear models, these characteristics are generalized as follows:

- At each set of values for the predictors, the response has a distribution that can be normal, binomial, Poisson, gamma, or inverse Gaussian, with parameters including a mean μ .
- A coefficient vector b defines a linear combination Xb of the predictors X .

- A *link function* f defines the model as $f(\mu) = Xb$.

Prepare Data

To begin fitting a regression, put your data into a form that fitting functions expect. All regression techniques begin with input data in an array X and response data in a separate vector y , or input data in a dataset array ds and response data as a column in ds . Each row of the input data represents one observation. Each column represents one predictor (variable).

For a dataset array ds , indicate the response variable with the 'ResponseVar' name-value pair:

```
mdl = LinearModel.fit(ds, 'ResponseVar', 'BloodPressure');  
% or  
mdl = GeneralizedLinearModel.fit(ds, 'ResponseVar', 'BloodPressure');
```

The response variable is the last column by default.

You can use numeric *categorical* predictors. A categorical predictor is one that takes values from a fixed set of possibilities.

- For a numeric array X , indicate the categorical predictors using the 'Categorical' name-value pair. For example, to indicate that predictors 2 and 3 out of six are categorical:

```
mdl = LinearModel.fit(X,y, 'Categorical', [2,3]);  
% or  
mdl = GeneralizedLinearModel.fit(X,y, 'Categorical', [2,3]);  
% or equivalently  
mdl = LinearModel.fit(X,y, 'Categorical', logical([0 1 1 0 0 0]));
```

- For a dataset array ds , fitting functions assume that these data types are categorical:
 - Logical
 - Categorical (nominal or ordinal)
 - String or character array

If you want to indicate that a numeric predictor is categorical, use the 'Categorical' name-value pair.

Represent missing numeric data as NaN. To represent missing data for other data types, see “Missing Group Values” on page 2-74.

- For a 'binomial' model with data matrix X , the response y can be:
 - Binary column vector — Each entry represents success (1) or failure (0).
 - Two-column matrix of integers — The first column is the number of successes in each observation, the second column is the number of trials in that observation.
- For a 'binomial' model with dataset ds :
 - Use the `ResponseVar` name-value pair to specify the column of ds that gives the number of successes in each observation.
 - Use the `BinomialSize` name-value pair to specify the column of ds that gives the number of trials in each observation.

Dataset Array for Input and Response Data

For example, to create a dataset array from an Excel spreadsheet:

```
ds = dataset('XLSFile','hospital.xls',...
            'ReadObsNames',true);
```

To create a dataset array from workspace variables:

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
```

Numeric Matrix for Input Data, Numeric Vector for Response

For example, to create numeric arrays from workspace variables:

```
load carsmall
X = [Weight Horsepower Cylinders Model_Year];
y = MPG;
```

To create numeric arrays from an Excel spreadsheet:

```
[X Xnames] = xlsread('hospital.xls');
y = X(:,4); % response y is systolic pressure
```

```
X(:,4) = []; % remove y from the X matrix
```

Notice that the nonnumeric entries, such as `sex`, do not appear in `X`.

Choose Generalized Linear Model and Link Function

Often, your data suggests the distribution type of the generalized linear model.

Response Data Type	Suggested Model Distribution Type
Any real number	'normal'
Any positive number	'gamma' or 'inverse gaussian'
Any nonnegative integer	'poisson'
Integer from 0 to n , where n is a fixed positive value	'binomial'

Set the model distribution type with the `Distribution` name-value pair. After selecting your model type, choose a link function to map between the mean μ and the linear predictor Xb .

Value	Description
'comloglog'	$\log(-\log((1-\mu))) = Xb$
'identity', default for the distribution 'normal'	$\mu = Xb$
'log', default for the distribution 'poisson'	$\log(\mu) = Xb$
'logit', default for the distribution 'binomial'	$\log(\mu/(1-\mu)) = Xb$
'loglog'	$\log(-\log(\mu)) = Xb$
'probit'	$\Phi^{-1}(\mu) = Xb$, where Φ is the normal (Gaussian) CDF function
'reciprocal', default for the distribution 'gamma'	$\mu^{-1} = Xb$

Value	Description
p (a number), default for the distribution 'inverse gaussian' (with $p = -2$)	$\mu^p = Xb$
Cell array of the form {FL FD FI}, containing three function handles, created using @, that define the link (FL), the derivative of the link (FD), and the inverse link (FI). Equivalently, can be a structure of function handles with field Link containing FL, field Derivative containing FD, and field Inverse containing FI.	User-specified link function (see “Custom Link Function” on page 9-145)

The nondefault link functions are mainly useful for binomial models. These nondefault link functions are 'comloglog', 'loglog', and 'probit'.

Custom Link Function

The link function defines the relationship $f(\mu) = Xb$ between the mean response μ and the linear combination $Xb = X*b$ of the predictors. You can choose one of the built-in link functions or define your own by specifying the link function FL, its derivative FD, and its inverse FI:

- The link function FL calculates $f(\mu)$.
- The derivative of the link function FD calculates $df(\mu)/d\mu$.
- The inverse function FI calculates $g(Xb) = \mu$.

You can specify a custom link function in either of two equivalent ways. Each way contains function handles that accept a single array of values representing μ or Xb , and returns an array the same size. The function handles are either in a cell array or a structure:

- Cell array of the form {FL FD FI}, containing three function handles, created using @, that define the link (FL), the derivative of the link (FD), and the inverse link (FI).
- Structure `s` with three fields, each containing a function handle created using @:
 - `s.Link` — Link function
 - `s.Derivative` — Derivative of the link function
 - `s.Inverse` — Inverse of the link function

For example, to fit a model using the 'probit' link function:

```
x = [2100 2300 2500 2700 2900 ...
     3100 3300 3500 3700 3900 4100 4300]';
n = [48 42 31 34 31 21 23 23 21 16 17 21]';
y = [1 2 0 3 8 8 14 17 19 15 17 21]';
g = GeneralizedLinearModel.fit(x,[y n],...
    'linear','distr','binomial','link','probit')
```

```
g =
```

```
Generalized Linear regression model:
```

```
probit(y) ~ 1 + x1
Distribution = Binomial
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	-7.3628	0.66815	-11.02	3.0701e-28
x1	0.0023039	0.00021352	10.79	3.8274e-27

```
12 observations, 10 error degrees of freedom
```

```
Dispersion: 1
```

```
Chi^2-statistic vs. constant model: 241, p-value = 2.25e-54
```

You can perform the same fit using a custom link function that performs identically to the 'probit' link function:

```
s = {@norminv,@(x)1./normpdf(norminv(x)),@normcdf};
g = GeneralizedLinearModel.fit(x,[y n],...
    'linear','distr','binomial','link',s)
```

```
g =
```

```
Generalized Linear regression model:
```

```
link(y) ~ 1 + x1
Distribution = Binomial
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	-7.3628	0.66815	-11.02	3.0701e-28
x1	0.0023039	0.00021352	10.79	3.8274e-27

```
12 observations, 10 error degrees of freedom
```

```
Dispersion: 1
```

```
Chi^2-statistic vs. constant model: 241, p-value = 2.25e-54
```

The two models are the same.

Equivalently, you can write `s` as a structure instead of a cell array of function handles:

```
s.Link = @norminv;
s.Derivative = @(x) 1./normpdf(norminv(x));
s.Inverse = @normcdf;
g = GeneralizedLinearModel.fit(x,[y n],...
    'linear','distr','binomial','link',s)
```

```
g =
```

```
Generalized Linear regression model:
```

```
link(y) ~ 1 + x1
Distribution = Binomial
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	-7.3628	0.66815	-11.02	3.0701e-28
x1	0.0023039	0.00021352	10.79	3.8274e-27

```
12 observations, 10 error degrees of freedom
```

```
Dispersion: 1
```

```
Chi^2-statistic vs. constant model: 241, p-value = 2.25e-54
```

Choose Fitting Method and Model

There are two ways to create a fitted model.

- Use `GeneralizedLinearModel.fit` when you have a good idea of your generalized linear model, or when you want to adjust your model later to include or exclude certain terms.
- Use `GeneralizedLinearModel.stepwise` when you want to fit your model using stepwise regression. `GeneralizedLinearModel.stepwise` starts from one model, such as a constant, and adds or subtracts terms one at a time, choosing an optimal term each time in a greedy fashion, until it cannot improve further. Use stepwise fitting to find a good model, one that has only relevant terms.

The result depends on the starting model. Usually, starting with a constant model leads to a small model. Starting with more terms can lead to a more complex model, but one that has lower mean squared error.

In either case, provide a model to the fitting function (which is the starting model for `GeneralizedLinearModel.stepwise`).

Specify a model using one of these methods.

- “Brief String” on page 9-148
- “Terms Matrix” on page 9-149
- “Formula” on page 9-152

Brief String

String	Model Type
'constant'	Model contains only a constant (intercept) term.
'linear'	Model contains an intercept and linear terms for each predictor.
'interactions'	Model contains an intercept, linear terms, and all products of pairs of distinct predictors (no squared terms).

String	Model Type
'purequadratic'	Model contains an intercept, linear terms, and squared terms.
'quadratic'	Model contains an intercept, linear terms, interactions, and squared terms.
'polyijk'	Model is a polynomial with all terms up to degree i in the first predictor, degree j in the second predictor, etc. Use numerals 0 through 9. For example, 'poly2111' has a constant plus all linear and product terms, and also contains terms with predictor 1 squared.

Terms Matrix

A terms matrix is a T -by- $P+1$ matrix specifying terms in a model, where T is the number of terms, P is the number of predictor variables, and plus one is for the response variable. The value of $T(i, j)$ is the exponent of variable j in term i . For example, if there are three predictor variables A , B , and C :

```
[0 0 0 0] % constant term or intercept
[0 1 0 0] % B; equivalently, A^0 * B^1 * C^0
[1 0 1 0] % A*C
[2 0 0 0] % A^2
[0 1 2 0] % B*(C^2)
```

The 0 at the end of each term represents the response variable. In general,

- If you have the variables in a dataset array, then a 0 must represent the response variable depending on the position of the response variable in the dataset array. For example:

Load sample data and define the dataset array.

```
load hospital
ds = dataset(hospital.Sex,hospital.BloodPressure(:,1),hospital.Age,...
hospital.Smoker,'VarNames',{'Sex','BloodPressure','Age','Smoker'});
```

Represent the linear model 'BloodPressure ~ 1 + Sex + Age + Smoker' in a terms matrix. The response variable is in the second column

of the data set array, so there must be a column of zeros for the response variable in the second column of the term matrix.

```
T = [0 0 0 0;1 0 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```

0     0     0     0
1     0     0     0
0     0     1     0
0     0     0     1
```

Redefine the dataset array.

```
ds = dataset(hospital.BloodPressure(:,1),hospital.Sex,hospital.Age,...
hospital.Smoker,'VarNames',{'BloodPressure','Sex','Age','Smoker'});
```

Now, the response variable is the first term in the data set array. Specify the same linear model, 'BloodPressure ~ 1 + Sex + Age + Smoker', using a term matrix.

```
T = [0 0 0 0;0 1 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```

0     0     0     0
0     1     0     0
0     0     1     0
0     0     0     1
```

- If you have the predictor and response variables in a matrix and column vector, then you must include a 0 for the response variable at the end of each term. For example:

Load sample data and define the matrix of predictors.

```
load carsmall
X = [Acceleration,Weight];
```

Specify the model 'MPG ~ Acceleration + Weight + Acceleration:Weight + Weight^2' using a term matrix and fit the model to data. This model includes the main effect and two way

interaction terms for the variables, Acceleration and Weight, and a second order term for the variable, Weight.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0;0 2 0]
```

```
T =
```

```

0    0    0
1    0    0
0    1    0
1    1    0
0    2    0

```

Fit a linear model.

```
mdl = LinearModel.fit(X,MPG,T)
```

```
mdl =
```

```
Linear regression model:
```

```
y ~ 1 + x1*x2 + x2^2
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	48.906	12.589	3.8847	0.00019665
x1	0.54418	0.57125	0.95261	0.34337
x2	-0.012781	0.0060312	-2.1192	0.036857
x1:x2	-0.00010892	0.00017925	-0.6076	0.545
x2^2	9.7518e-07	7.5389e-07	1.2935	0.19917

```
Number of observations: 94, Error degrees of freedom: 89
```

```
Root Mean Squared Error: 4.1
```

```
R-squared: 0.751, Adjusted R-Squared 0.739
```

```
F-statistic vs. constant model: 67, p-value = 4.99e-26
```

Only the intercept and x2 term, which corresponds to the Weight variable, are significant at the 5% significance level.

Now, perform a stepwise regression with a constant model as the starting model and a linear model with interactions as the upper model.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0];
mdl = LinearModel.stepwise(X,MPG,[0 0 0],'upper',T)
```

1. Adding x2, FStat = 259.3087, pValue = 1.643351e-28

```
mdl =
```

Linear regression model:

$y \sim 1 + x2$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	49.238	1.6411	30.002	2.7015e-49
x2	-0.0086119	0.0005348	-16.103	1.6434e-28

Number of observations: 94, Error degrees of freedom: 92

Root Mean Squared Error: 4.13

R-squared: 0.738, Adjusted R-Squared 0.735

F-statistic vs. constant model: 259, p-value = 1.64e-28

The results of the stepwise regression are consistent with the results of `LinearModel.fit` in the previous step.

Formula

A formula for a model specification is a string of the form

```
'Y ~ terms',
```

- Y is the response name.
- *terms* contains
 - Variable names
 - + to include the next variable
 - - to exclude the next variable
 - : to define an interaction, a product of terms
 - * to define an interaction and all lower-order terms

- \wedge to raise the predictor to a power, exactly as in $*$ repeated, so \wedge includes lower order terms as well
- $()$ to group terms

Tip Formulas include a constant (intercept) term by default. To exclude a constant term from the model, include -1 in the formula.

Examples:

' $Y \sim A + B + C$ ' is a three-variable linear model with intercept.

' $Y \sim A + B + C - 1$ ' is a three-variable linear model without intercept.

' $Y \sim A + B + C + B^2$ ' is a three-variable model with intercept and a B^2 term.

' $Y \sim A + B^2 + C$ ' is the same as the previous example, since B^2 includes a B term.

' $Y \sim A + B + C + A:B$ ' includes an $A*B$ term.

' $Y \sim A*B + C$ ' is the same as the previous example, since $A*B = A + B + A:B$.

' $Y \sim A*B*C - A:B:C$ ' has all interactions among A , B , and C , except the three-way interaction.

' $Y \sim A*(B + C + D)$ ' has all linear terms, plus products of A with each of the other variables.

Fit Model to Data

Create a fitted model using `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`. Choose between them as in “Choose Fitting Method and Model” on page 9-148. For generalized linear models other than those with a normal distribution, give a `Distribution` name-value pair as in “Choose Generalized Linear Model and Link Function” on page 9-144. For example,

```
mdl = GeneralizedLinearModel.fit(X,y,'linear','Distribution','poisson')
% or
mdl = GeneralizedLinearModel.fit(X,y,'quadratic',...
    'Distribution','binomial')
```

Examine Quality and Adjust the Fitted Model

After fitting a model, examine the result.

- “Model Display” on page 9-154
- “Diagnostic Plots” on page 9-155
- “Residuals — Model Quality for Training Data” on page 9-158
- “Plots to Understand Predictor Effects and How to Modify a Model” on page 9-161

Model Display

A linear regression model shows several diagnostics when you enter its name or enter `disp mdl`. This display gives some of the basic information to check whether the fitted model represents the data adequately.

For example, fit a Poisson model to data constructed with two out of five predictors not affecting the response, and with no intercept term:

```
rng('default') % for reproducibility
X = randn(100,5);
mu = exp(X(:, [1 4 5]) * [.4; .2; .3]);
y = poissrnd(mu);
mdl = GeneralizedLinearModel.fit(X,y,...
    'linear', 'Distribution', 'poisson')
```

```
mdl =
```

```
Generalized Linear regression model:
```

```
log(y) ~ 1 + x1 + x2 + x3 + x4 + x5
Distribution = Poisson
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	0.039829	0.10793	0.36901	0.71212
x1	0.38551	0.076116	5.0647	4.0895e-07
x2	-0.034905	0.086685	-0.40266	0.6872
x3	-0.17826	0.093552	-1.9054	0.056722
x4	0.21929	0.09357	2.3436	0.019097

x5	0.28918	0.1094	2.6432	0.0082126
----	---------	--------	--------	-----------

100 observations, 94 error degrees of freedom
 Dispersion: 1
 Chi^2-statistic vs. constant model: 44.9, p-value = 1.55e-08

Notice that:

- The display contains the estimated values of each coefficient in the `Estimate` column. These values are reasonably near the true values `[0; .4; 0; 0; .2; .3]`, except possibly the coefficient of `x3` is not terribly near 0.
- There is a standard error column for the coefficient estimates.
- The reported `pValue` (which are derived from the t statistics under the assumption of normal errors) for predictors 1, 4, and 5 are small. These are the three predictors that were used to create the response data `y`.
- The `pValue` for `(Intercept)`, `x2` and `x3` are larger than 0.01. These three predictors were not used to create the response data `y`. The `pValue` for `x3` is just over .05, so might be regarded as possibly significant.
- The display contains the Chi-square statistic.

Diagnostic Plots

Diagnostic plots help you identify outliers, and see other problems in your model or fit. To illustrate these plots, consider binomial regression with a logistic link function.

The *logistic model* is useful for proportion data. It defines the relationship between the proportion p and the weight w by:

$$\log[p/(1 - p)] = b_1 + b_2 w$$

This example fits a binomial model to data. The data are derived from `carbig.mat`, which contains measurements of large cars of various weights. Each weight in `w` has a corresponding number of cars in `total` and a corresponding number of poor-mileage cars in `poor`.

It is reasonable to assume that the values of poor follow binomial distributions, with the number of trials given by total and the percentage of successes depending on w. This distribution can be accounted for in the context of a logistic model by using a generalized linear model with link function $\log(\mu/(1-\mu)) = Xb$. This link function is called 'logit'.

```
w = [2100 2300 2500 2700 2900 3100 ...
     3300 3500 3700 3900 4100 4300]';
total = [48 42 31 34 31 21 23 23 21 16 17 21]';
poor = [1 2 0 3 8 8 14 17 19 15 17 21]';
mdl = GeneralizedLinearModel.fit(w,[poor total],...
    'linear','Distribution','binomial','link','logit')
```

```
mdl =
```

```
Generalized Linear regression model:
```

```
logit(y) ~ 1 + x1
Distribution = Binomial
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	-13.38	1.394	-9.5986	8.1019e-22
x1	0.0041812	0.00044258	9.4474	3.4739e-21

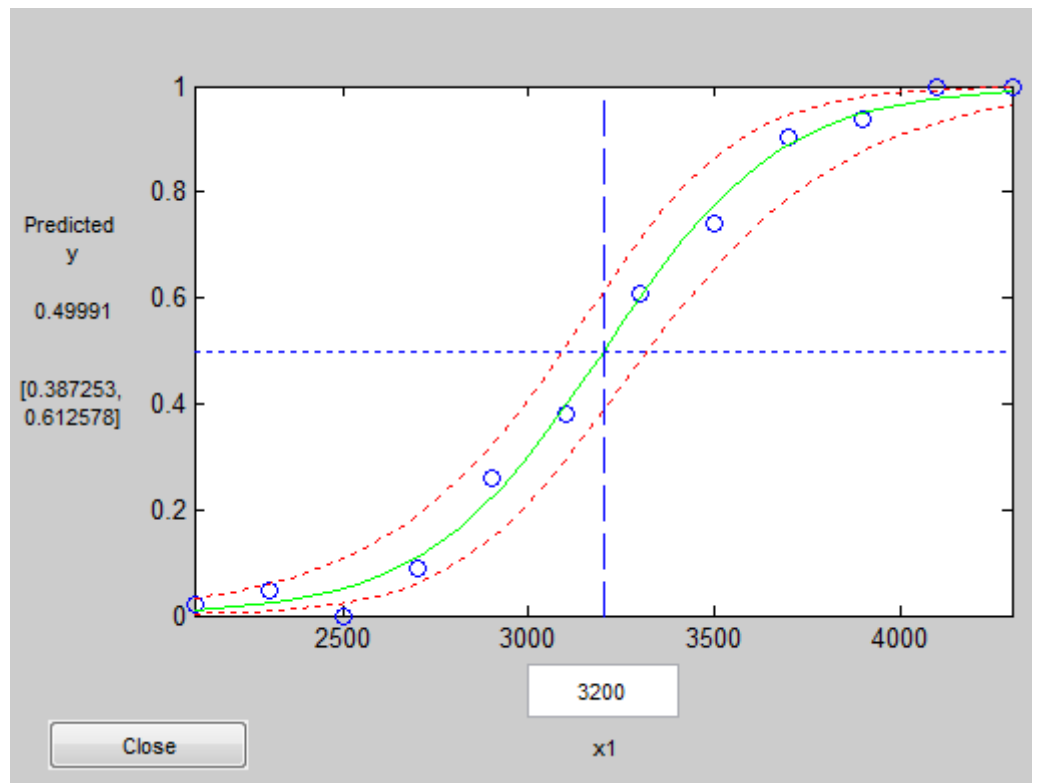
```
12 observations, 10 error degrees of freedom
```

```
Dispersion: 1
```

```
Chi^2-statistic vs. constant model: 242, p-value = 1.3e-54
```

See how well the model fits the data.

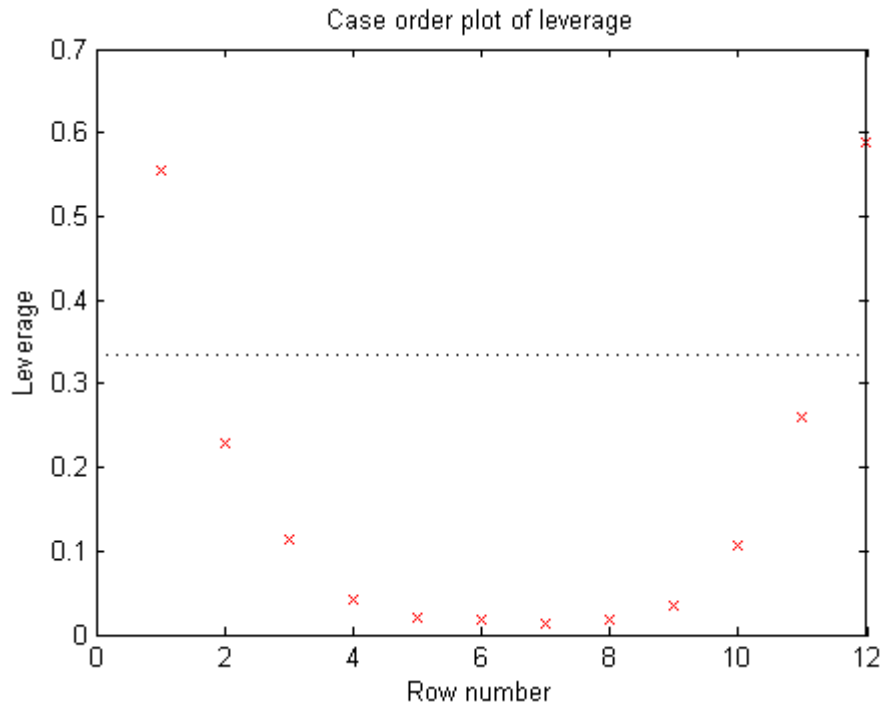
```
plotSlice(mdl)
```



The fit looks reasonably good, with fairly wide confidence bounds.

To examine further details, create a leverage plot.

```
plotDiagnostics(md1)
```



This is typical of a regression with points ordered by the predictor variable. The leverage of each point on the fit is higher for points with relatively extreme predictor values (in either direction) and low for points with average predictor values. In examples with multiple predictors and with points not ordered by predictor value, this plot can help you identify which observations have high leverage because they are outliers as measured by their predictor values.

Residuals – Model Quality for Training Data

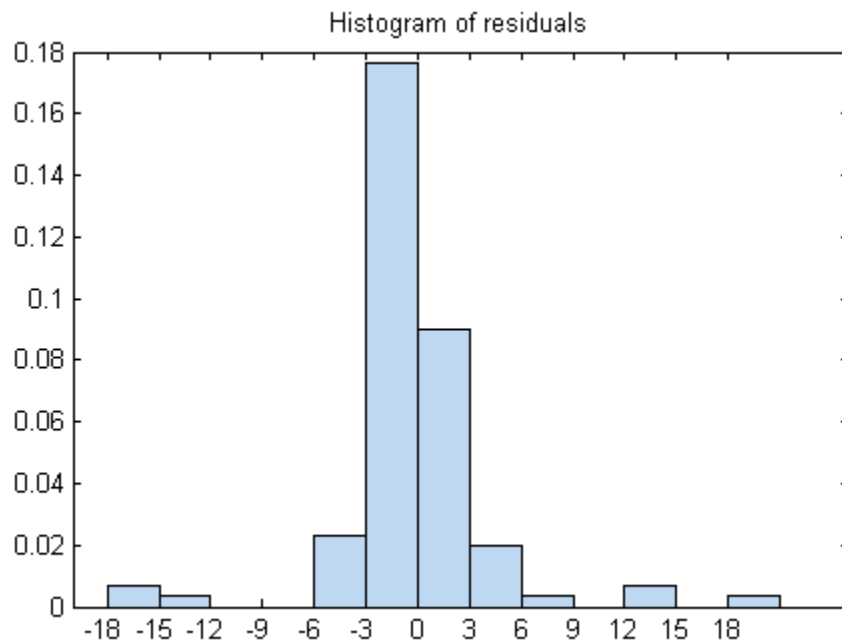
There are several residual plots to help you discover errors, outliers, or correlations in the model or data. The simplest residual plots are the default histogram plot, which shows the range of the residuals and their frequencies, and the probability plot, which shows how the distribution of the residuals compares to a normal distribution with matched variance.

This example shows residual plots for a fitted Poisson model. The data construction has two out of five predictors not affecting the response, and no intercept term:

```
rng('default') % for reproducibility
X = randn(100,5);
mu = exp(X(:,[1 4 5])*[2;1;.5]));
y = poissrnd(mu);
mdl = GeneralizedLinearModel.fit(X,y,...
    'linear','Distribution','poisson');
```

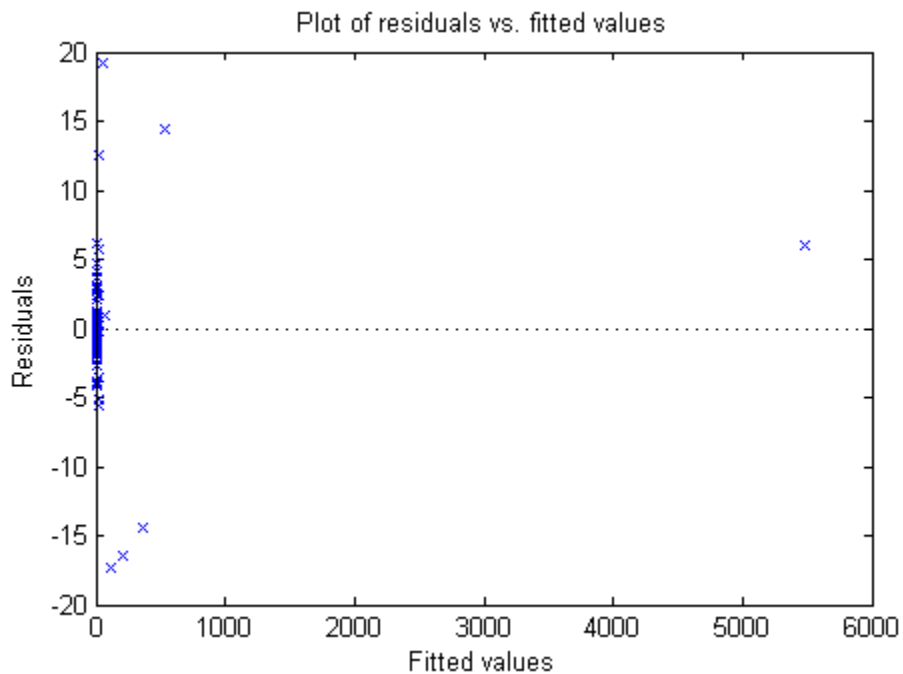
Examine the residuals:

```
plotResiduals(mdl)
```



While most residuals cluster near 0, there are several near ± 18 . So examine a different residuals plot.

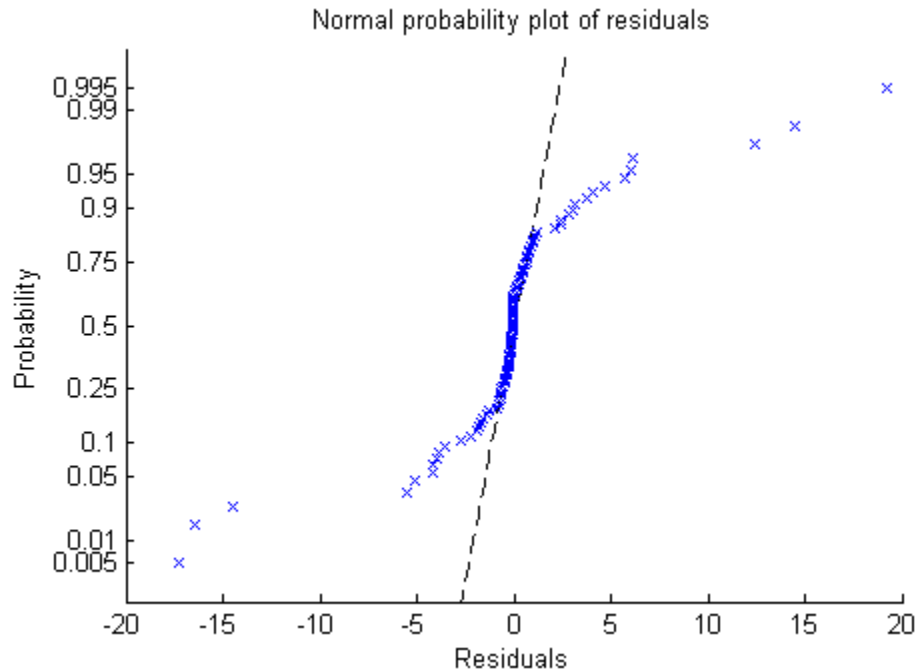
```
plotResiduals mdl, 'fitted'
```



The large residuals don't seem to have much to do with the sizes of the fitted values.

Perhaps a probability plot is more informative.

```
plotResiduals mdl, 'probability'
```

Now it is clear. The residuals do not follow a normal distribution. Instead, they have fatter tails, much as an underlying Poisson distribution.

Plots to Understand Predictor Effects and How to Modify a Model

This example shows how to understand the effect each predictor has on a regression model, and how to modify the model to remove unnecessary terms.

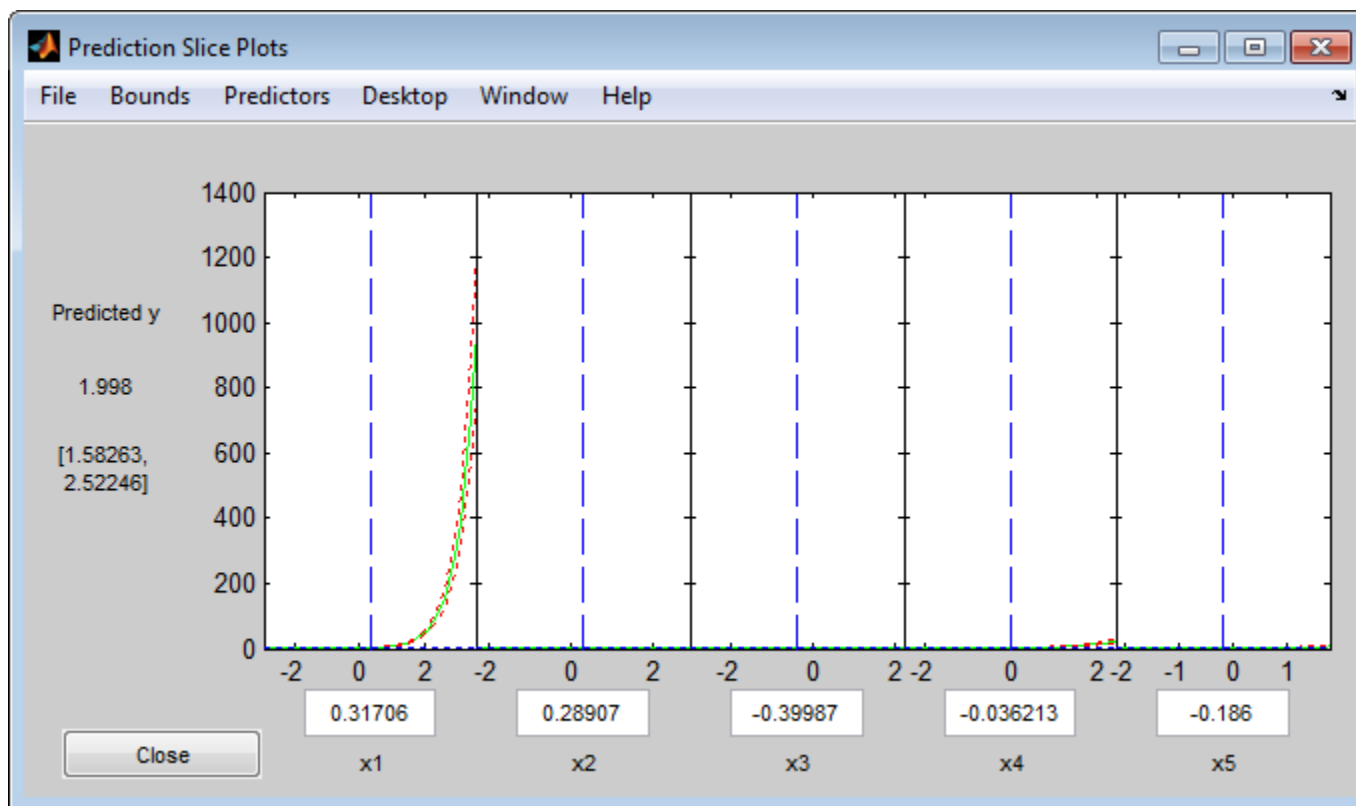
- 1 Create a model from some predictors in artificial data. The data do not use the second and third columns in X . So you expect the model not to show much dependence on those predictors.

```
rng('default') % for reproducibility
X = randn(100,5);
mu = exp(X(:,[1 4 5])*[2;1;.5]);
y = poissrnd(mu);
mdl = GeneralizedLinearModel.fit(X,y,...
```

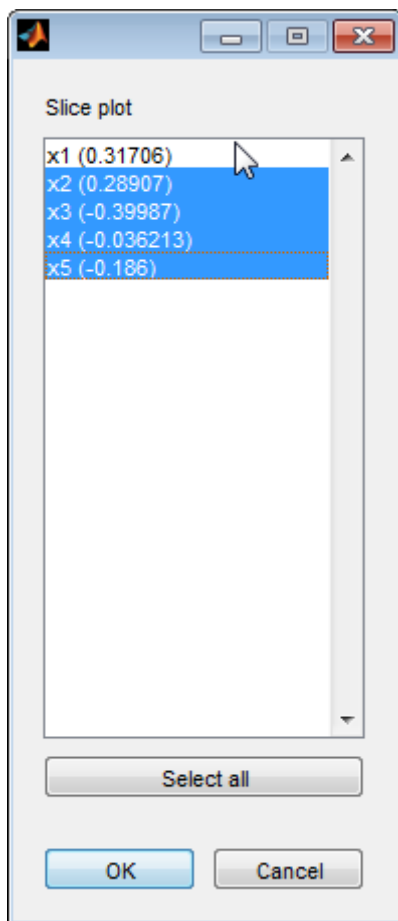
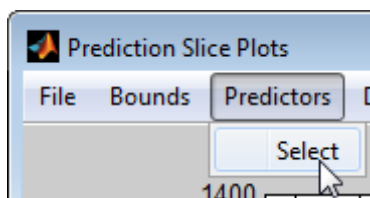
```
'linear', 'Distribution', 'poisson');
```

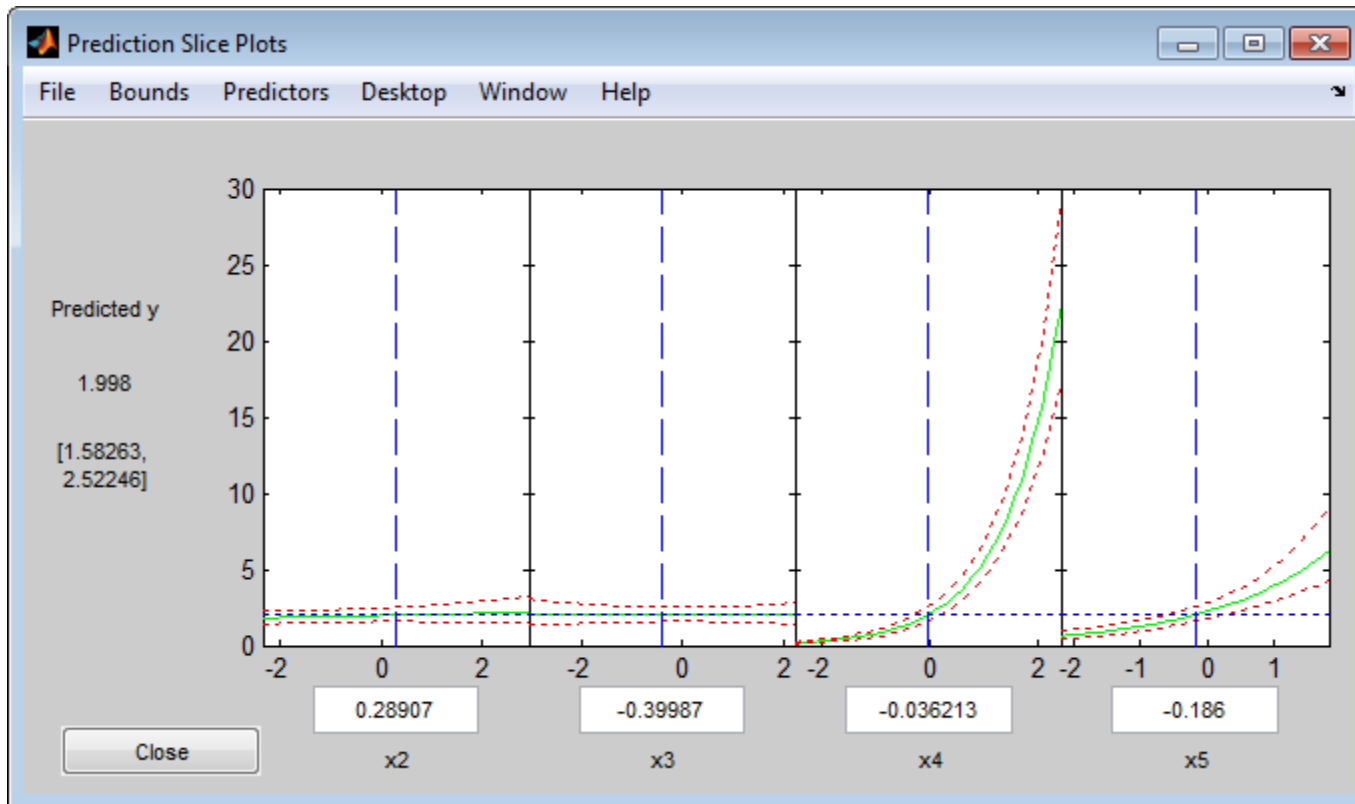
- 2 Examine a slice plot of the responses. This displays the effect of each predictor separately.

```
plotSlice mdl
```



The scale of the first predictor is overwhelming the plot. Disable it using the **Predictors** menu.





Now it is clear that predictors 2 and 3 have little to no effect.

You can drag the individual predictor values, which are represented by dashed blue vertical lines. You can also choose between simultaneous and non-simultaneous confidence bounds, which are represented by dashed red curves. Dragging the predictor lines confirms that predictors 2 and 3 have little to no effect.

- 3 Remove the unnecessary predictors using either `removeTerms` or `step`. Using `step` can be safer, in case there is an unexpected importance to a term that becomes apparent after removing another term. However, sometimes `removeTerms` can be effective when `step` does not proceed. In this case, the two give identical results.

```
mdl1 = removeTerms(mdl, 'x2 + x3')
```

```
mdl1 =
```

Generalized Linear regression model:

$\log(y) \sim 1 + x1 + x4 + x5$

Distribution = Poisson

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	0.17604	0.062215	2.8295	0.004662
x1	1.9122	0.024638	77.614	0
x4	0.98521	0.026393	37.328	5.6696e-305
x5	0.61321	0.038435	15.955	2.6473e-57

100 observations, 96 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 4.97e+04, p-value = 0

```
mdl1 = step(mdl, 'NSteps', 5, 'Upper', 'linear')
```

1. Removing x3, Deviance = 93.856, Chi2Stat = 0.00075551, PValue = 0.97807

2. Removing x2, Deviance = 96.333, Chi2Stat = 2.4769, PValue = 0.11553

```
mdl1 =
```

Generalized Linear regression model:

$\log(y) \sim 1 + x1 + x4 + x5$

Distribution = Poisson

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	0.17604	0.062215	2.8295	0.004662
x1	1.9122	0.024638	77.614	0
x4	0.98521	0.026393	37.328	5.6696e-305
x5	0.61321	0.038435	15.955	2.6473e-57

```

100 observations, 96 error degrees of freedom
Dispersion: 1
Chi^2-statistic vs. constant model: 4.97e+04, p-value = 0

```

Predict or Simulate Responses to New Data

There are three ways to use a linear model to predict the response to new data:

- “predict” on page 9-166
- “feval” on page 9-167
- “random” on page 9-168

predict

The `predict` method gives a prediction of the mean responses and, if requested, confidence bounds.

This example shows how to predict and obtain confidence intervals on the predictions using the `predict` method.

- 1 Create a model from some predictors in artificial data. The data do not use the second and third columns in X . So you expect the model not to show much dependence on these predictors. Construct the model stepwise to include the relevant predictors automatically.

```

rng('default') % for reproducibility
X = randn(100,5);
mu = exp(X(:,[1 4 5])*[2;1;.5]);
y = poissrnd(mu);
mdl = GeneralizedLinearModel.stepwise(X,y,...
    'constant','upper','linear','Distribution','poisson');

```

```

1. Adding x1, Deviance = 2515.02869, Chi2Stat = 47242.9622, PValue = 0
2. Adding x4, Deviance = 328.39679, Chi2Stat = 2186.6319, PValue = 0
3. Adding x5, Deviance = 96.3326, Chi2Stat = 232.0642, PValue = 2.114384e-52

```

- 2 Generate some new data, and evaluate the predictions from the data.

```

Xnew = randn(3,5) + repmat([1 2 3 4 5],[3,1]); % new data
[ynew,ynewci] = predict(mdl,Xnew)

```

```
ynew =
    1.0e+04 *
    0.1130
    1.7375
    3.7471
```

```
ynewci =
    1.0e+04 *
    0.0821    0.1555
    1.2167    2.4811
    2.8419    4.9407
```

feval

When you construct a model from a dataset array, `feval` is often more convenient for predicting mean responses than `predict`. However, `feval` does not provide confidence bounds.

This example shows how to predict mean responses using the `feval` method.

- 1 Create a model from some predictors in artificial data. The data do not use the second and third columns in X . So you expect the model not to show much dependence on these predictors. Construct the model stepwise to include the relevant predictors automatically.

```
rng('default') % for reproducibility
X = randn(100,5);
mu = exp(X(:,[1 4 5])*[2;1;.5]));
y = poissrnd(mu);
ds = dataset({X,'x1','x2','x3','x4','x5'},{y,'y'});
mdl = GeneralizedLinearModel.stepwise(ds,...
    'constant','upper','linear','Distribution','poisson');
```

1. Adding x1, Deviance = 2515.02869, Chi2Stat = 47242.9622, PValue = 0
2. Adding x4, Deviance = 328.39679, Chi2Stat = 2186.6319, PValue = 0
3. Adding x5, Deviance = 96.3326, Chi2Stat = 232.0642, PValue = 2.114384e-52

2 Generate some new data, and evaluate the predictions from the data.

```
Xnew = randn(3,5) + repmat([1 2 3 4 5],[3,1]); % new data  
ynew = feval mdl,Xnew(:,1),Xnew(:,4),Xnew(:,5)) % only need predictors 1,
```

```
ynew =
```

```
1.0e+04 *
```

```
0.1130
```

```
1.7375
```

```
3.7471
```

Equivalently,

```
ynew = feval(mdl,Xnew(:,[1 4 5])) % only need predictors 1,4,5
```

```
ynew =
```

```
1.0e+04 *
```

```
0.1130
```

```
1.7375
```

```
3.7471
```

random

The `random` method generates new random response values for specified predictor values. The distribution of the response values is the distribution used in the model. `random` calculates the mean of the distribution from the predictors, estimated coefficients, and link function. For distributions such as normal, the model also provides an estimate of the variance of the response. For the binomial and Poisson distributions, the variance of the response is determined by the mean; `random` does not use a separate “dispersion” estimate.

This example shows how to simulate responses using the `random` method.

1 Create a model from some predictors in artificial data. The data do not use the second and third columns in `X`. So you expect the model not to show

much dependence on these predictors. Construct the model stepwise to include the relevant predictors automatically.

```
rng('default') % for reproducibility
X = randn(100,5);
mu = exp(X(:,[1 4 5])*[2;1;.5]);
y = poissrnd(mu);
mdl = GeneralizedLinearModel.stepwise(X,y,...
    'constant','upper','linear','Distribution','poisson');
```

1. Adding x1, Deviance = 2515.02869, Chi2Stat = 47242.9622, PValue = 0
2. Adding x4, Deviance = 328.39679, Chi2Stat = 2186.6319, PValue = 0
3. Adding x5, Deviance = 96.3326, Chi2Stat = 232.0642, PValue = 2.114384e-52

2 Generate some new data, and evaluate the predictions from the data.

```
Xnew = randn(3,5) + repmat([1 2 3 4 5],[3,1]); % new data
ysim = random(mdl,Xnew)
```

```
ysim =

    1111
    17121
    37457
```

The predictions from random are Poisson samples, so are integers.

3 Evaluate the random method again, the result changes.

```
ysim = random(mdl,Xnew)
```

```
ysim =

    1175
    17320
    37126
```

Share Fitted Models

The model display contains enough information to enable someone else to recreate the model in a theoretical sense. For example,

```
rng('default') % for reproducibility
```

```
X = randn(100,5);
mu = exp(X(:,[1 4 5])*[2;1;.5]);
y = poissrnd(mu);
mdl = GeneralizedLinearModel.stepwise(X,y,...
    'constant','upper','linear','Distribution','poisson')
```

1. Adding x1, Deviance = 2515.02869, Chi2Stat = 47242.9622, PValue = 0
2. Adding x4, Deviance = 328.39679, Chi2Stat = 2186.6319, PValue = 0
3. Adding x5, Deviance = 96.3326, Chi2Stat = 232.0642, PValue = 2.114384e-52

```
mdl =
```

```
Generalized Linear regression model:
```

```
log(y) ~ 1 + x1 + x4 + x5
Distribution = Poisson
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	0.17604	0.062215	2.8295	0.004662
x1	1.9122	0.024638	77.614	0
x4	0.98521	0.026393	37.328	5.6696e-305
x5	0.61321	0.038435	15.955	2.6473e-57

```
100 observations, 96 error degrees of freedom
```

```
Dispersion: 1
```

```
Chi^2-statistic vs. constant model: 4.97e+04, p-value = 0
```

You can access the model description programmatically, too. For example,

```
mdl.Coefficients.Estimate
```

```
ans =
```

```
0.1760
1.9122
0.9852
0.6132
```

```
mdl.Formula
```

```
ans =
```

```
log(y) ~ 1 + x1 + x4 + x5
```

Generalized Linear Model Workflow

This example shows a typical workflow: import data, fit a generalized linear model, test its quality, modify it to improve the quality, and make predictions based on the model. It computes the probability that a flower is in one of two classes, based on the Fisher iris data.

Step 1. Load the data.

Load the Fisher iris data. Extract the rows that have classification versicolor or virginica. These are rows 51 to 150. Create logical response variables that are true for versicolor flowers.

```
load fisheriris
X = meas(51:end,:); % versicolor and virginica
y = strcmp('versicolor',species(51:end));
```

Step 2. Fit a generalized linear model.

Fit a binomial generalized linear model to the data.

```
mdl = GeneralizedLinearModel.fit(X,y,'linear',...
    'distr','binomial')
```

```
mdl =
```

```
Generalized Linear regression model:
```

```
logit(y) ~ 1 + x1 + x2 + x3 + x4
Distribution = Binomial
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	42.638	25.708	1.6586	0.097204
x1	2.4652	2.3943	1.0296	0.30319
x2	6.6809	4.4796	1.4914	0.13585
x3	-9.4294	4.7372	-1.9905	0.046537
x4	-18.286	9.7426	-1.8769	0.060529

```
100 observations, 95 error degrees of freedom
Dispersion: 1
Chi^2-statistic vs. constant model: 127, p-value = 1.95e-26
```

Step 3. Examine the result, consider alternative models.

Some p -values in the `pValue` column are not very small. Perhaps the model can be simplified.

See if some 95% confidence intervals for the coefficients include 0. If so, perhaps these model terms could be removed.

```
confint = coefCI mdl
```

```
confint =
   -8.3984   93.6740
   -2.2881    7.2185
   -2.2122   15.5739
  -18.8339   -0.0248
  -37.6277    1.0554
```

Only two of the predictors have coefficients whose confidence intervals do not include 0.

The coefficients of 'x1' and 'x2' have the largest p -values. Test whether both coefficients could be zero.

```
M = [0 1 0 0 0      % picks out coefficient for column 1
      0 0 1 0 0];  % picks out coefficient for column 2
p = coefTest(mdl,M)
```

```
p =
      0.1442
```

The p -value of about 0.14 is not very small. Drop those terms from the model.

```
mdl1 = removeTerms(mdl, 'x1 + x2')
```

```
mdl1 =
```

```
Generalized Linear regression model:
```

```
logit(y) ~ 1 + x3 + x4
Distribution = Binomial
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	45.272	13.612	3.326	0.00088103
x3	-5.7545	2.3059	-2.4956	0.012576
x4	-10.447	3.7557	-2.7816	0.0054092

100 observations, 97 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 118, p-value = 2.3e-26

Perhaps it would have been better to have
`GeneralizedLinearModel.stepwise` identify the model initially.

```
mdl2 = GeneralizedLinearModel.stepwise(X,y,...
    'constant', 'Distribution', 'binomial', 'upper', 'linear')
```

1. Adding x4, Deviance = 33.4208, Chi2Stat = 105.2086, PValue = 1.099298e-24

2. Adding x3, Deviance = 20.5635, Chi2Stat = 12.8573, PValue = 0.000336166

3. Adding x2, Deviance = 13.2658, Chi2Stat = 7.29767, PValue = 0.00690441

mdl2 =

Generalized Linear regression model:

```
logit(y) ~ 1 + x2 + x3 + x4
Distribution = Binomial
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	50.527	23.995	2.1057	0.035227
x2	8.3761	4.7612	1.7592	0.078536
x3	-7.8745	3.8407	-2.0503	0.040334
x4	-21.43	10.707	-2.0014	0.04535

100 observations, 96 error degrees of freedom

Dispersion: 1

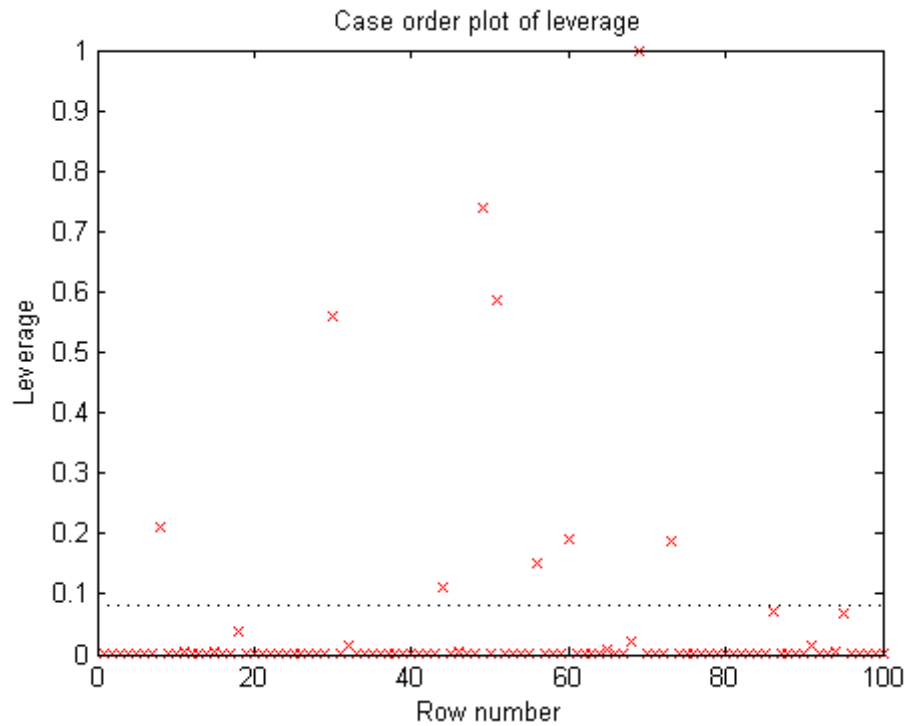
Chi²-statistic vs. constant model: 125, p-value = 5.4e-27

GeneralizedLinearModel.stepwise included 'x2' in the model, because it neither adds nor removes terms with p -values between 0.05 and 0.10.

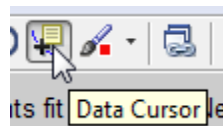
Step 4. Look for outliers and exclude them.

Examine a leverage plot to look for influential outliers.

```
plotDiagnostics(md12, 'leverage')
```



There is one observation with a leverage close to one. Using the Data Cursor, click the point, and find it has index 69.



See if the model coefficients change when you fit a model excluding this point.

```
oldCoeffs = mdl2.Coefficients.Estimate;
mdl3 = GeneralizedLinearModel.fit(X,y,'linear',...
    'distr','binomial','pred',2:4,'exclude',69);
newCoeffs = mdl3.Coefficients.Estimate;
disp([oldCoeffs newCoeffs])
```

```
    50.5268    50.5268
     8.3761     8.3761
    -7.8745    -7.8745
   -21.4296   -21.4296
```

The model coefficients do not change, suggesting that the response at the high-leverage point is consistent with the predicted value from the reduced model.

Step 5. Predict the probability that a new flower is versicolor.

Use `mdl2` to predict the probability that a flower with average measurements is versicolor. Generate confidence intervals for your prediction.

```
[newf newc] = predict(mdl2,mean(X))
```

```
newf =
    0.5086
```

```
newc =
    0.1863    0.8239
```

The model gives almost a 50% probability that the average flower is versicolor, with a wide confidence interval about this estimate.

Lasso Regularization of Generalized Linear Models

In this section...

“What is Generalized Linear Model Lasso Regularization?” on page 9-176

“Regularize Poisson Regression” on page 9-176

“Regularize Logistic Regression” on page 9-180

“Regularize Wide Data in Parallel” on page 9-187

“Generalized Linear Model Lasso and Elastic Net” on page 9-193

“References” on page 9-195

What is Generalized Linear Model Lasso Regularization?

Lasso is a regularization technique. Use `lasso1m` to:

- Reduce the number of predictors in a generalized linear model.
- Identify important predictors.
- Select among redundant predictors.
- Produce shrinkage estimates with potentially lower predictive errors than ordinary least squares.

Elastic net is a related technique. Use it when you have several highly correlated variables. `lasso1m` provides elastic net regularization when you set the Alpha name-value pair to a number strictly between 0 and 1.

For details about lasso and elastic net computations and algorithms, see “Generalized Linear Model Lasso and Elastic Net” on page 9-193. For a discussion of generalized linear models, see “What Are Generalized Linear Models?” on page 9-141.

Regularize Poisson Regression

This example shows how to identify and remove redundant predictors from a generalized linear model.

Create data with 20 predictors, and Poisson responses using just three of the predictors, plus a constant.

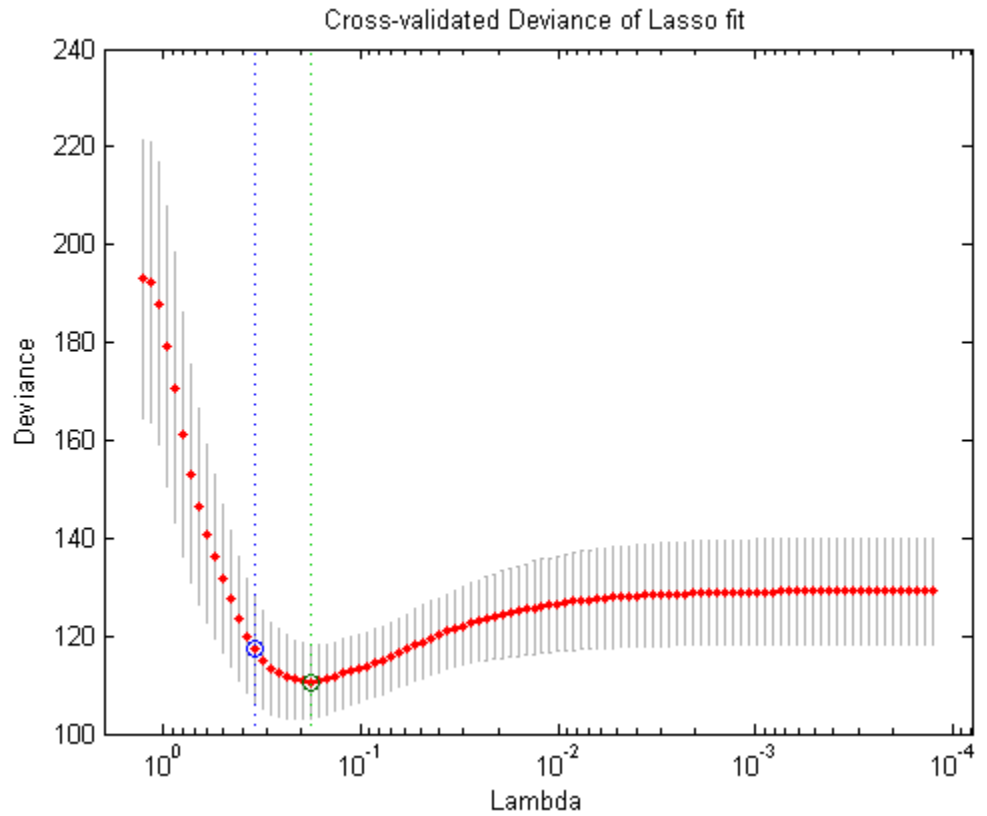
```
rng('default') % for reproducibility
X = randn(100,20);
mu = exp(X(:, [5 10 15]) * [.4;.2;.3] + 1);
y = poissrnd(mu);
```

Construct a cross-validated lasso regularization of a Poisson regression model of the data.

```
[B FitInfo] = lassoglm(X,y,'poisson','CV',10);
```

Examine the cross-validation plot to see the effect of the Lambda regularization parameter.

```
lassoPlot(B,FitInfo,'plottype','CV');
```



The green circle and dashed line locate the λ with minimal cross-validation error. The blue circle and dashed line locate the point with minimal cross-validation error plus one standard deviation.

Find the nonzero model coefficients corresponding to the two identified points.

```
minpts = find(B(:,FitInfo.IndexMinDeviance))
```

```
minpts =
```

- 3
- 5
- 6

```

10
11
15
16

```

```
min1pts = find(B(:,FitInfo.Index1SE))
```

```
min1pts =
```

```

5
10
15

```

The coefficients from the minimal plus one standard error point are exactly those coefficients used to create the data.

Find the values of the model coefficients at the minimal plus one standard error point.

```
B(min1pts,FitInfo.Index1SE)
```

```
ans =
```

```

0.2903
0.0789
0.2081

```

The values of the coefficients are, as expected, smaller than the original $[0.4, 0.2, 0.3]$. Lasso works by “shrinkage,” which biases predictor coefficients toward zero. See “Lasso and Elastic Net Details” on page 9-131.

The constant term is in the `FitInfo.Intercept` vector.

```
FitInfo.Intercept(FitInfo.Index1SE)
```

```
ans =
```

```
1.0879
```

The constant term is near 1, which is the value used to generate the data.

Regularize Logistic Regression

This example shows a workflow for regularizing binomial regression. The default (canonical) link function for binomial regression is the logistic function.

Step 1. Prepare the data.

Load the `ionosphere` data. The response `Y` is a cell array of 'g' or 'b' strings. Convert the cells to logical values, with `true` representing 'g'. Remove the first two columns of `X` because they have some awkward statistical properties, which are beyond the scope of this discussion.

```
load ionosphere
Ybool = strcmp(Y, 'g');
X = X(:,3:end);
```

Step 2. Create a cross-validated fit.

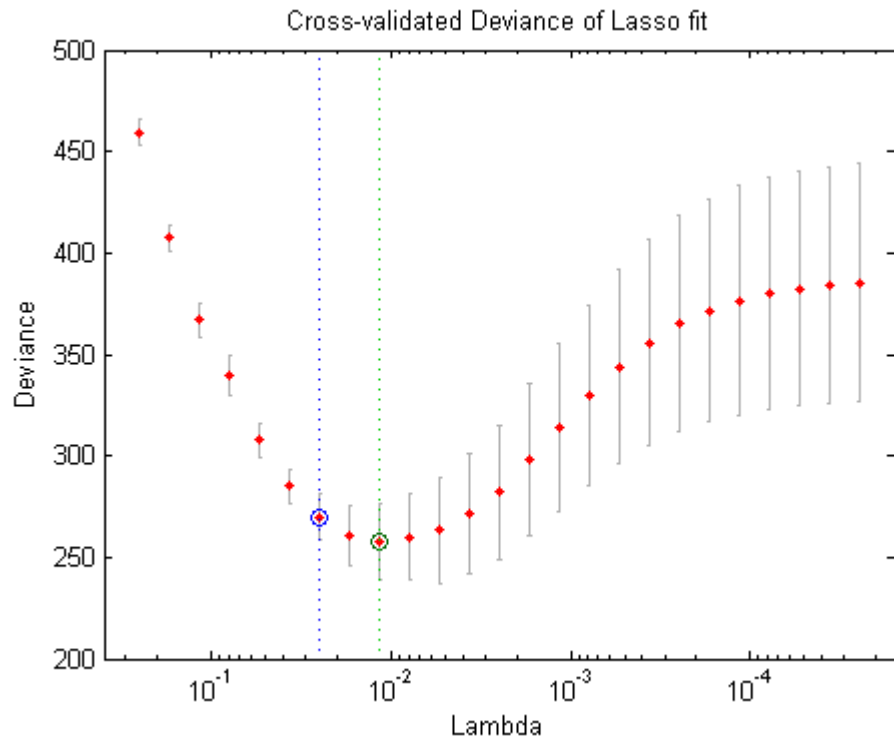
Construct a regularized binomial regression using 25 Lambda values and 10-fold cross validation. This process can take a few minutes.

```
rng('default') % for reproducibility
[B,FitInfo] = lassoglm(X,Ybool,'binomial',...
    'NumLambda',25,'CV',10);
```

Step 3. Examine plots to find appropriate regularization.

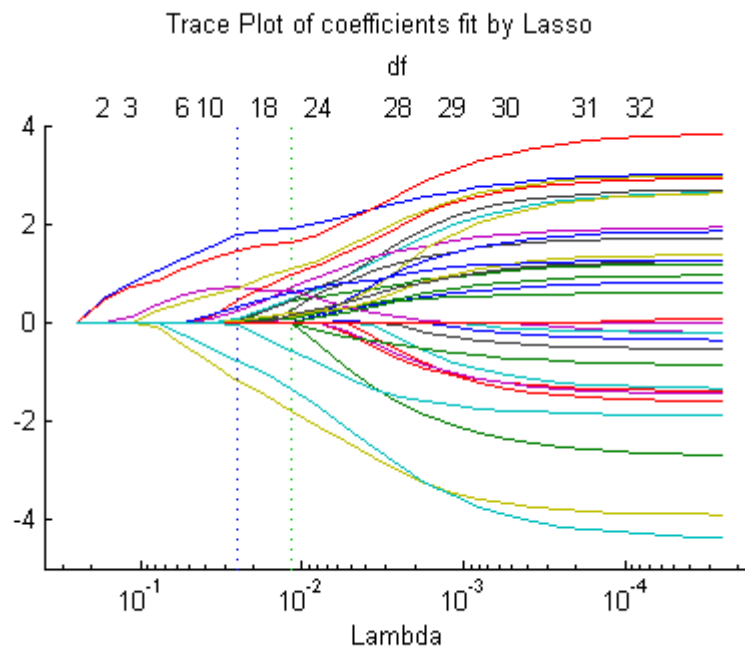
`lassoPlot` can give both a standard trace plot and a cross-validated deviance plot. Examine both plots.

```
lassoPlot(B,FitInfo,'PlotType','CV');
```



The plot identifies the minimum-deviance point with a green circle and dashed line as a function of the regularization parameter λ . The blue circled point has minimum deviance plus no more than one standard deviation.

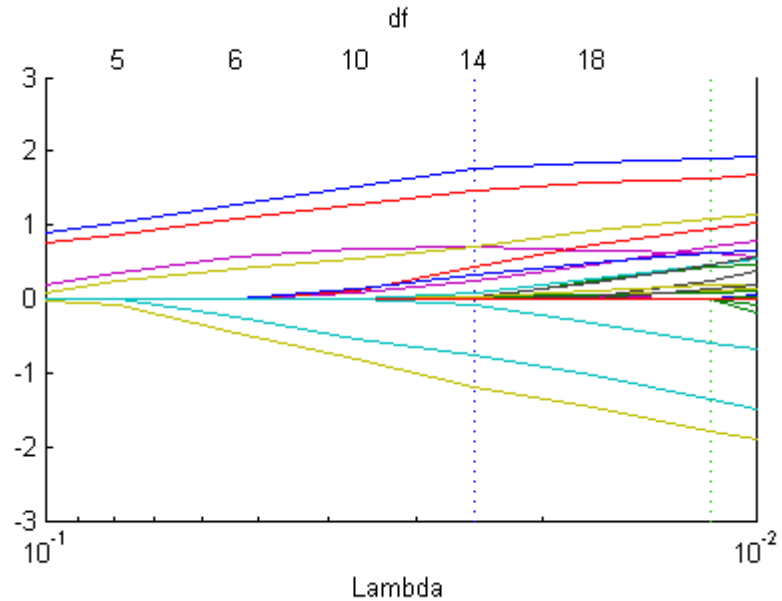
```
lassoPlot(B,FitInfo,'PlotType','Lambda','XScale','log');
```



The trace plot shows nonzero model coefficients as a function of the regularization parameter Lambda . Because there are 32 predictors and a linear model, there are 32 curves. As Lambda increases to the left, `lasso1m` sets various coefficients to zero, removing them from the model.

The trace plot is somewhat compressed. Zoom in to see more detail.

```
xlim([.01 .1])
ylim([-3 3])
```



As Lambda increases toward the left side of the plot, fewer nonzero coefficients remain.

Find the number of nonzero model coefficients at the Lambda value with minimum deviance plus one standard deviation point. The regularized model coefficients are in column `FitInfo.Index1SE` of the B matrix.

```
indx = FitInfo.Index1SE;
B0 = B(:,indx);
nonzeros = sum(B0 ~= 0)
```

```
nonzeros =
```

```
14
```

When you set `Lambda` to `FitInfo.Index1SE`, `lassoglm` removes over half of the 32 original predictors.

Step 4. Create a regularized model.

The constant term is in the `FitInfo.Index1SE` entry of the `FitInfo.Intercept` vector. Call that value `cnst`.

The model is $\text{logit}(\mu) = \log(\mu/(1 - \mu))X*B0 + \text{cnst}$. Therefore, for predictions, $\mu = \exp(X*B0 + \text{cnst}) / (1 + \exp(x*B0 + \text{cnst}))$.

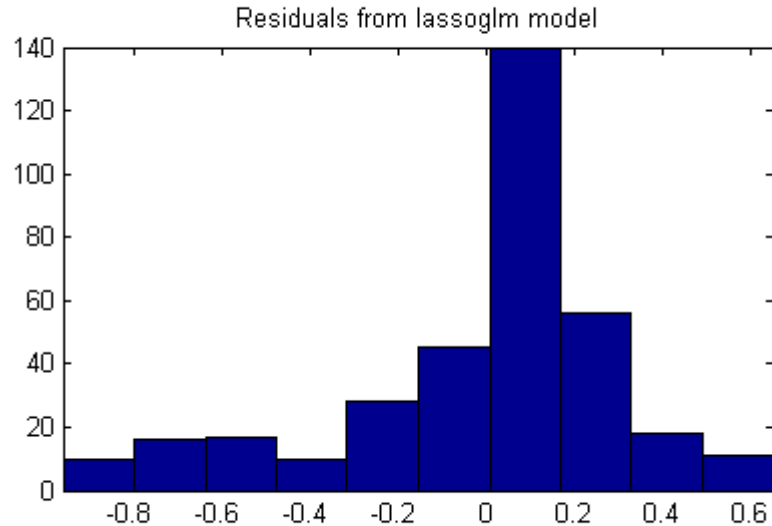
The `glmval` function evaluates model predictions. It assumes that the first model coefficient relates to the constant term. Therefore, create a coefficient vector with the constant term first.

```
cnst = FitInfo.Intercept(indx);  
B1 = [cnst;B0];
```

Step 5. Examine residuals.

Plot the training data against the model predictions for the regularized `lassoglm` model.

```
preds = glmval(B1,X,'logit');  
hist(Ybool - preds) % plot residuals  
title('Residuals from lassoglm model')
```

Step 6. Alternative: Use identified predictors in a least-squares generalized linear model.

Instead of using the biased predictions from the model, you can make an unbiased model using just the identified predictors.

```
predictors = find(B0); % indices of nonzero predictors
mdl = GeneralizedLinearModel.fit(X,Ybool,'linear',...
    'Distribution','binomial','PredictorVars',predictors)

mdl =
```

```
Generalized Linear regression model:
y ~ [Linear formula with 15 terms in 14 predictors]
Distribution = Binomial
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	-2.9367	0.50926	-5.7666	8.0893e-09
x1	2.492	0.60795	4.099	4.1502e-05
x3	2.5501	0.63304	4.0284	5.616e-05
x4	0.48816	0.50336	0.9698	0.33215
x5	0.6158	0.62192	0.99015	0.3221
x6	2.294	0.5421	4.2317	2.3198e-05
x7	0.77842	0.57765	1.3476	0.1778
x12	1.7808	0.54316	3.2786	0.0010432
x16	-0.070993	0.50515	-0.14054	0.88823
x20	-2.7767	0.55131	-5.0365	4.7402e-07
x24	2.0212	0.57639	3.5067	0.00045372
x25	-2.3796	0.58274	-4.0835	4.4363e-05
x27	0.79564	0.55904	1.4232	0.15467
x29	1.2689	0.55468	2.2876	0.022162
x32	-1.5681	0.54336	-2.8859	0.0039035

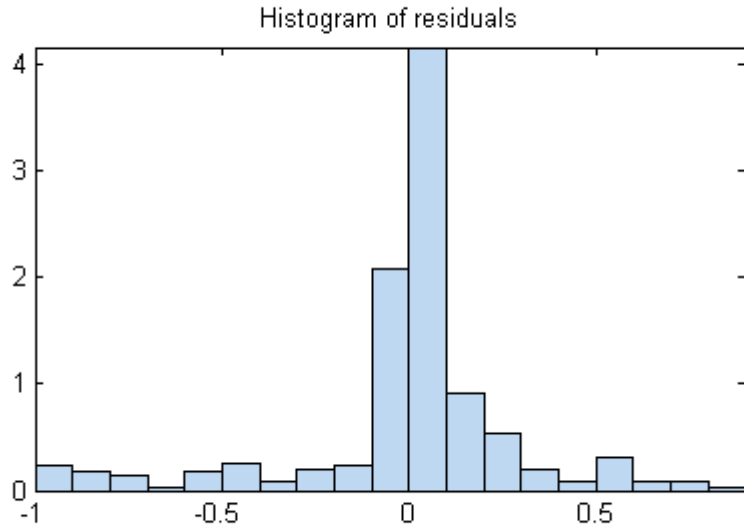
351 observations, 336 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 262, p-value = 1e-47

Plot the residuals of the model.

`plotResiduals mdl`



As expected, residuals from the least-squares model are slightly smaller than those of the regularized model. However, this does not mean that `mdl` is a better predictor for new data.

Regularize Wide Data in Parallel

This example shows how to regularize a model with many more predictors than observations. *Wide data* is data with more predictors than observations. Typically, with wide data you want to identify important predictors. Use `lasso glm` as an exploratory or screening tool to select a smaller set of variables to prioritize your modeling and research. Use parallel computing to speed up cross validation.

Load the `ovariancancer` data. This data has 216 observations and 4000 predictors in the `obs` workspace variable. The responses are binary, either

'Cancer' or 'Normal', in the grp workspace variable. Convert the responses to binary for use in `lassoglm`.

```
load ovariancancer
y = strcmp(grp,'Cancer');
```

Set options to use parallel computing. Prepare to compute in parallel using `matlabpool`.

```
opt = statset('UseParallel','always');
matlabpool open 4
```

```
Starting matlabpool using the 'local' profile ...
connected to 4 labs.
```

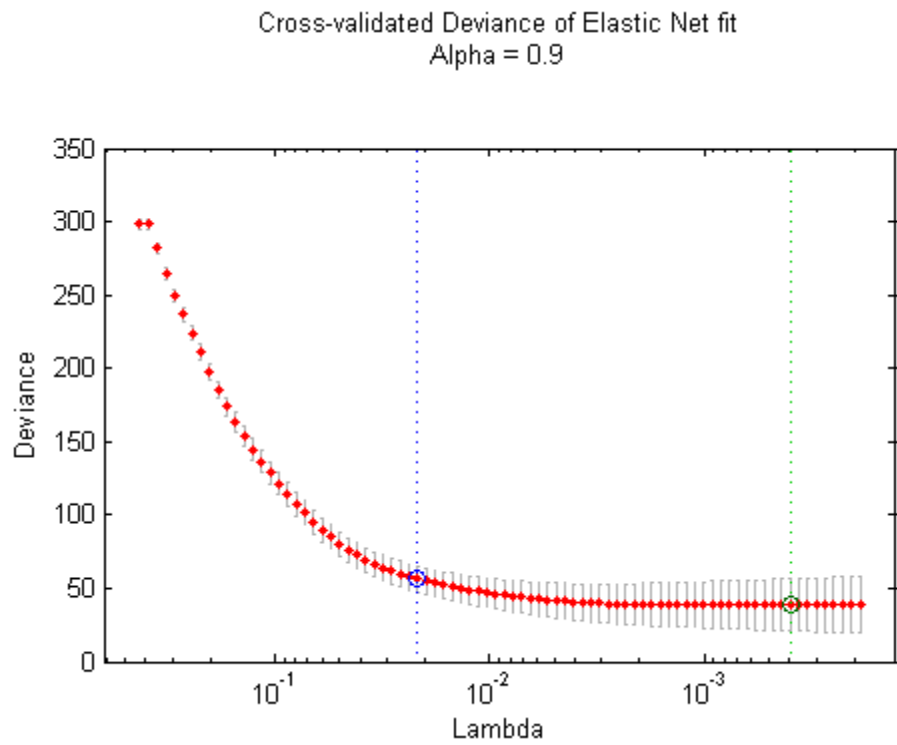
Fit a cross-validated set of regularized models. Use the `Alpha` parameter to favor retaining groups of highly correlated predictors, as opposed to eliminating all but one member of the group. Commonly, you use a relatively large value of `Alpha`.

```
rng('default') % for reproducibility
tic
[B,S] = lassoglm(obs,y,'binomial','NumLambda',100, ...
    'Alpha',0.9,'LambdaRatio',1e-4,'CV',10,'Options',opt);
toc
```

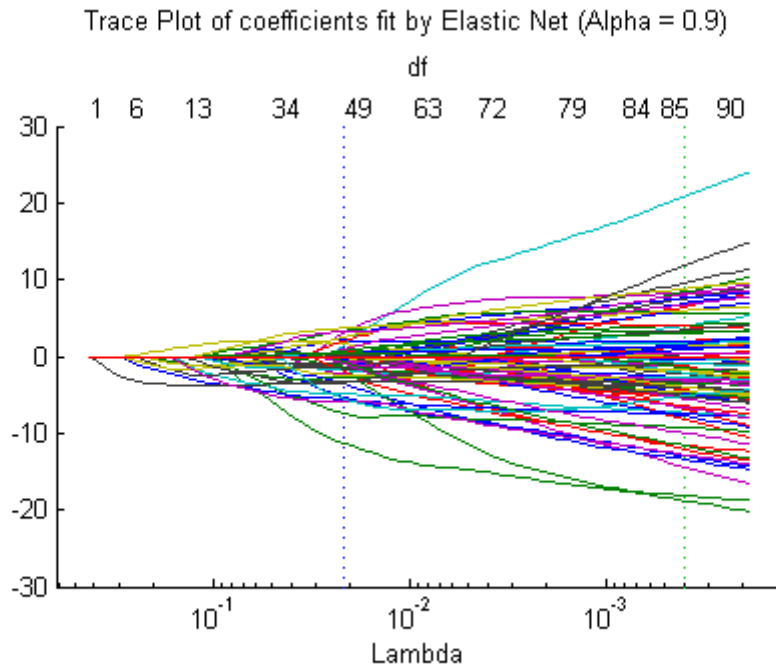
```
Elapsed time is 480.451777 seconds.
```

Examine trace and cross-validation plots.

```
lassoPlot(B,S,'PlotType','CV');
```



```
lassoPlot(B,S,'PlotType','Lambda','XScale','log')
```



The right (green) vertical dashed line represents the Lambda providing the smallest cross-validated deviance. The left (blue) dashed line has the minimal deviance plus no more than one standard deviation. This blue line has many fewer predictors:

```
[S.DF(S.Index1SE) S.DF(S.IndexMinDeviance)]
```

```
ans =
```

```
50 86
```

You asked `lasso1m` to fit using 100 different Lambda values. How many did it use?

```
size(B)
```

```
ans =
      4000      84
```

`lassoglm` stopped after 84 values because the deviance was too small for small Lambda values. To avoid overfitting, `lassoglm` halts when the deviance of the fitted model is too small compared to the deviance in the binary responses, ignoring the predictor variables.

You can force `lassoglm` to include more terms by explicitly providing a set of Lambda values.

```
minLambda = min(S.Lambda);
explicitLambda = [minLambda* [.1 .01 .001] S.Lambda];
[B2,S2] = lassoglm(obs,y,'binomial','Lambda',explicitLambda,...
    'LambdaRatio',1e-4, 'CV',10,'Options',opt);
length(S2.Lambda)
```

```
ans =
      87
```

`lassoglm` used the three smaller values in fitting.

To save time, you can use:

- Fewer Lambda, meaning fewer fits
- Fewer cross-validation folds
- A larger value for LambdaRatio

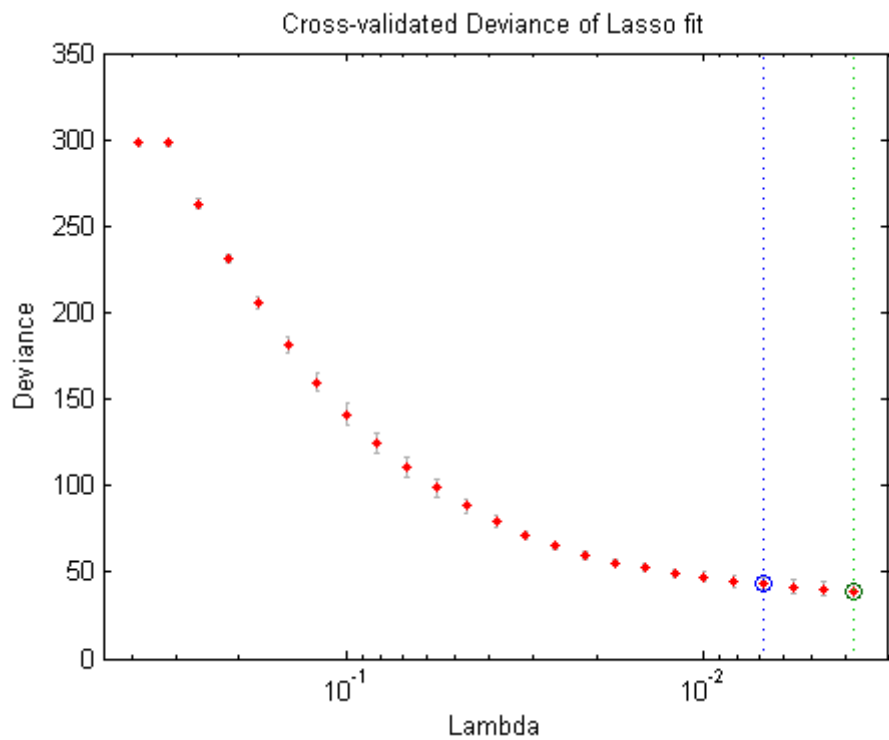
Use serial computation and all three of these time-saving methods:

```
tic
[Bquick,Squick] = lassoglm(obs,y,'binomial','NumLambda',25,...
    'LambdaRatio',1e-2,'CV',5);
toc
```

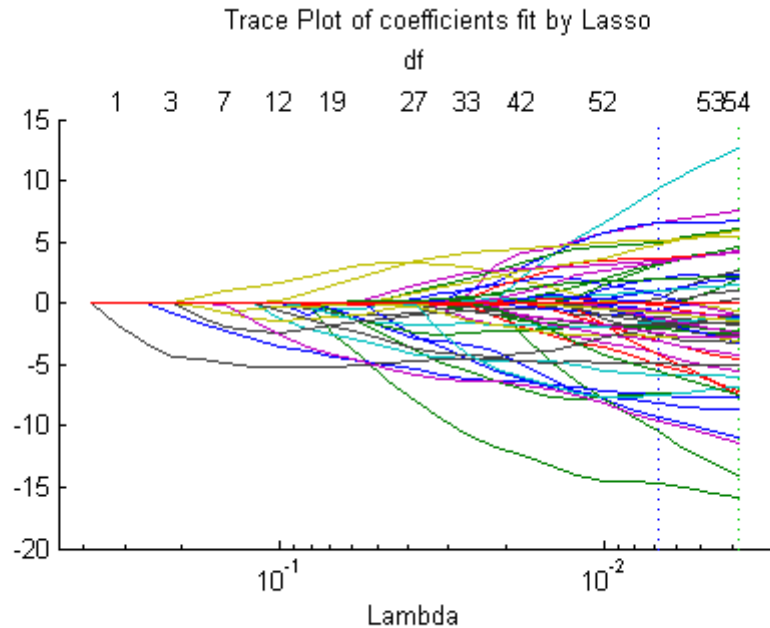
Elapsed time is 51.708074 seconds.

Graphically compare the new results to the first results.

```
lassoPlot(Bquick,Squick,'PlotType','CV');
```



```
lassoPlot(Bquick,Squick,'PlotType','Lambda','XScale','log')
```

The number of nonzero coefficients in the lowest plus one standard deviation model is around 50, similar to the first computation.

Generalized Linear Model Lasso and Elastic Net

Overview of Lasso and Elastic Net

Lasso is a regularization technique for estimating generalized linear models. Lasso includes a penalty term that constrains the size of the estimated coefficients. Therefore, it resembles ridge regression. Lasso is a *shrinkage estimator*: it generates coefficient estimates that are biased to be small. Nevertheless, a lasso estimator can have smaller error than an ordinary maximum likelihood estimator when you apply it to new data.

Unlike ridge regression, as the penalty term increases, the lasso technique sets more coefficients to zero. This means that the lasso estimator is a smaller

model, with fewer predictors. As such, lasso is an alternative to stepwise regression and other model selection and dimensionality reduction techniques.

Elastic net is a related technique. Elastic net is akin to a hybrid of ridge regression and lasso regularization. Like lasso, elastic net can generate reduced models by generating zero-valued coefficients. Empirical studies suggest that the elastic net technique can outperform lasso on data with highly correlated predictors.

Definition of Lasso for Generalized Linear Models

For a nonnegative value of λ , lasso solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{N} \text{Deviance}(\beta_0, \beta) + \lambda \sum_{j=1}^p |\beta_j| \right),$$

where

- Deviance is the deviance of the model fit to the responses using intercept β_0 and predictor coefficients β . The formula for Deviance depends on the `distr` parameter you supply to `lasso glm`. Minimizing the λ -penalized deviance is equivalent to maximizing the λ -penalized log likelihood.
- N is the number of observations.
- λ is a nonnegative regularization parameter corresponding to one value of `Lambda`.
- Parameters β_0 and β are scalar and p -vector respectively.

As λ increases, the number of nonzero components of β decreases.

The lasso problem involves the L^1 norm of β , as contrasted with the elastic net algorithm.

Definition of Elastic Net for Generalized Linear Models

For an α strictly between 0 and 1, and a nonnegative λ , elastic net solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{N} \text{Deviance}(\beta_0, \beta) + \lambda P_\alpha(\beta) \right),$$

where

$$P_\alpha(\beta) = \frac{(1-\alpha)}{2} \|\beta\|_2^2 + \alpha \|\beta\|_1 = \sum_{j=1}^p \left(\frac{(1-\alpha)}{2} \beta_j^2 + \alpha |\beta_j| \right).$$

Elastic net is the same as lasso when $\alpha = 1$. For other values of α , the penalty term $P_\alpha(\beta)$ interpolates between the L^1 norm of β and the squared L^2 norm of β . As α shrinks toward 0, elastic net approaches ridge regression.

References

- [1] Tibshirani, R. *Regression Shrinkage and Selection via the Lasso*. Journal of the Royal Statistical Society, Series B, Vol. 58, No. 1, pp. 267–288, 1996.
- [2] Zou, H. and T. Hastie. *Regularization and Variable Selection via the Elastic Net*. Journal of the Royal Statistical Society, Series B, Vol. 67, No. 2, pp. 301–320, 2005.
- [3] Friedman, J., R. Tibshirani, and T. Hastie. *Regularization Paths for Generalized Linear Models via Coordinate Descent*. Journal of Statistical Software, Vol. 33, No. 1, 2010. <http://www.jstatsoft.org/v33/i01>
- [4] Hastie, T., R. Tibshirani, and J. Friedman. *The Elements of Statistical Learning*, 2nd edition. Springer, New York, 2008.
- [5] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*, 2nd edition. Chapman & Hall/CRC Press, 1989.

Nonlinear Regression

In this section...

“What Are Parametric Nonlinear Regression Models?” on page 9-196

“Prepare Data” on page 9-197

“Represent the Nonlinear Model” on page 9-198

“Choose Initial Vector β_0 ” on page 9-201

“Fit Nonlinear Model to Data” on page 9-201

“Examine Quality and Adjust the Fitted Model” on page 9-202

“Predict or Simulate Responses to New Data” on page 9-206

“Nonlinear Regression Workflow” on page 9-210

What Are Parametric Nonlinear Regression Models?

Parametric nonlinear models represent the relationship between a continuous response variable and one or more continuous predictor variables in the form

$$y = f(X, \beta) + \varepsilon,$$

where

- y is an n -by-1 vector of observations of the response variable.
- f is any function of X and β that evaluates each row of X along with the vector β to compute the prediction for the corresponding row of y .
- X is an n -by- p matrix of predictors, with one row for each observation, and one column for each predictor.
- β is a p -by-1 vector of unknown parameters to be estimated.
- ε is an n -by-1 vector of independent, identically distributed random disturbances.

In contrast, nonparametric models do not attempt to characterize the relationship between predictors and response with model parameters. Descriptions are often graphical, as in the case of “Classification Trees and Regression Trees” on page 13-30.

`NonLinearModel.fit` attempts to find values of the parameters β that minimize the mean squared differences between the observed responses y and the predictions of the model $f(X,\beta)$. To do so, it needs a starting value `beta0` before iteratively modifying the vector β to a vector with minimal mean squared error.

Prepare Data

To begin fitting a regression, put your data into a form that fitting functions expect. All regression techniques begin with input data in an array X and response data in a separate vector y , or input data in a dataset array `ds` and response data as a column in `ds`. Each row of the input data represents one observation. Each column represents one predictor (variable).

For a dataset array `ds`, indicate the response variable with the 'ResponseVar' name-value pair:

```
mdl = LinearModel.fit(ds, 'ResponseVar', 'BloodPressure');
```

The response variable is the last column by default.

You cannot use numeric *categorical* predictors for nonlinear regression. A categorical predictor is one that takes values from a fixed set of possibilities.

Represent missing data as NaN for both input data and response data.

Dataset Array for Input and Response Data

For example, to create a dataset array from an Excel spreadsheet:

```
ds = dataset('XLSFile', 'hospital.xls', ...  
            'ReadObsNames', true);
```

To create a dataset array from workspace variables:

```
load carsmall  
ds = dataset(Weight, Model_Year, MPG n);
```

Numeric Matrix for Input Data and Numeric Vector for Response

For example, to create numeric arrays from workspace variables:

```
load carsmall
X = [Weight Horsepower Cylinders Model_Year];
y = MPG;
```

To create numeric arrays from an Excel spreadsheet:

```
[X Xnames] = xlsread('hospital.xls');
y = X(:,4); % response y is systolic pressure
X(:,4) = []; % remove y from the X matrix
```

Notice that the nonnumeric entries, such as `sex`, do not appear in `X`.

Represent the Nonlinear Model

There are several ways to represent a nonlinear model. Use whichever is most convenient.

The nonlinear model is a required input to `NonLinearModel.fit`, in the `modelfun` input.

`NonLinearModel.fit` assumes that the response function $f(X, \beta)$ is smooth in the parameters β . If your function is not smooth, `NonLinearModel.fit` can fail to provide optimal parameter estimates.

- “Function Handle to Anonymous Function or Function File” on page 9-198
- “String Representation of Formula” on page 9-200

Function Handle to Anonymous Function or Function File

The function handle `@modelfun(b, x)` accepts a vector `b` and matrix or dataset array `x`. The function handle should return a vector `f` with the same number of rows as `x`. For example, the function file `hougen.m` computes

$$\text{hougen}(b, x) = \frac{b(1)x(2) - x(3) / b(5)}{1 + b(2)x(1) + b(3)x(2) + b(4)x(3)}.$$

Examine the function by entering type `hougen` at the MATLAB command line.

```
function yhat = hougen(beta,x)
%HOUGEN Hougen-Watson model for reaction kinetics.
% YHAT = HOUGEN(BETA,X) gives the predicted values of the
% reaction rate, YHAT, as a function of the vector of
% parameters, BETA, and the matrix of data, X.
% BETA must have 5 elements and X must have three
% columns.
%
% The model form is:
%  $y = (b1*x2 - x3/b5) ./ (1+b2*x1+b3*x2+b4*x3)$ 
%
% Reference:
% [1] Bates, Douglas, and Watts, Donald, "Nonlinear
% Regression Analysis and Its Applications", Wiley
% 1988 p. 271-272.
%
% Copyright 1993-2004 The MathWorks, Inc.
% $Revision: 1.1.6.39.2.2 $ $Date: 2012/07/18 19:48:53 $
% B.A. Jones 1-06-95.

b1 = beta(1);
b2 = beta(2);
b3 = beta(3);
b4 = beta(4);
b5 = beta(5);

x1 = x(:,1);
x2 = x(:,2);
x3 = x(:,3);

yhat = (b1*x2 - x3/b5) ./ (1+b2*x1+b3*x2+b4*x3);
```

You can write an anonymous function that performs the same calculation as `hougen.m`.

```
modelfun = @(b,x)(b(1)*x(:,2) - x(:,3)/b(5))./...
(1 + b(2)*x(:,1) + b(3)*x(:,2) + b(4)*x(:,3));
```

String Representation of Formula

For data in a matrix X and response in a vector y :

- Represent the formula using 'x1' as the first predictor (column) in X , 'x2' as the second predictor, etc.
- Represent the vector of parameters to optimize as 'b1', 'b2', etc.
- Write the formula as 'y ~ (mathematical expressions)'.

For example, to represent the response to the reaction data:

```
modelfun = 'y ~ (b1*x2 - x3/b5)/(1 + b2*x1 + b3*x2 + b4*x3)';
```

For data in a dataset array, you can use formulas represented as strings with the variable names from the dataset array. Put the response variable name at the left of the formula, followed by a ~, followed by a string representing the response formula.

This example shows how to create a string to represent the response to the reaction data that is in a dataset array.

- 1 Load the reaction data.

```
load reaction
```

- 2 Put the data into a dataset array, where each variable has a name given in the x_n or y_n strings.

```
ds = dataset({reactants,xn(1,:),xn(2,:),xn(3,:)},...
            {rate,yn});
```

- 3 Examine the first row of the dataset array.

```
ds(1,:)
```

```
ans =
```

Hydrogen	n_Pentane	Isopentane	ReactionRate
470	300	10	8.55

- 4 Write the hougén formula using names in the dataset array.


```

modelfun = ['ReactionRate ~ (b1*n_Pentane - Isopentane/b5) / '...
' (1 + Hydrogen*b2 + n_Pentane*b3 + Isopentane*b4)']

modelfun =
ReactionRate ~ (b1*n_Pentane - Isopentane/b5) / ...
(1 + Hydrogen*b2 + n_Pentane*b3 + Isopentane*b4)

```

Choose Initial Vector beta0

The initial vector for the fitting iterations, `beta0`, can greatly influence the quality of the resulting fitted model. `beta0` gives the dimensionality of the problem, meaning it needs the correct length. A good choice of `beta0` leads to a quick, reliable model, while a poor choice can lead to a long computation, or to an inadequate model.

It is difficult to give advice on choosing a good `beta0`. If you believe certain components of the vector should be positive or negative, set your `beta0` to have those characteristics. If you know the approximate value of other components, include them in `beta0`. However, if you don't know good values, try a random vector, such as

```

beta0 = randn(nVars,1);
% or
beta0 = 10*rand(nVars,1);

```

Fit Nonlinear Model to Data

The syntax for fitting a nonlinear regression model using a dataset array `ds` is

```
mdl = NonLinearModel.fit(ds,modelfun,beta0)
```

The syntax for fitting a nonlinear regression model using a numeric array `X` and numeric response vector `y` is

```
mdl = NonLinearModel.fit(X,y,modelfun,beta0)
```

For information on representing the input parameters, see “Prepare Data” on page 9-197, “Represent the Nonlinear Model” on page 9-198, and “Choose Initial Vector `beta0`” on page 9-201.

`NonLinearModel.fit` assumes that the response variable in a dataset array `ds` is the last column. To change this, use the `ResponseVar` name-value pair to name the response column.

Examine Quality and Adjust the Fitted Model

There are diagnostic plots to help you examine the quality of a model.

- `plotDiagnostics mdl` gives a variety of plots, including leverage and Cook's distance plots.
- `plotResiduals mdl` gives the difference between the fitted model and the data.

There are also properties of `mdl` that relate to the model quality.

- `mdl.RMSE` gives the root mean square error between the data and the fitted model.
- `mdl.Residuals.Raw` gives the raw residuals.
- `mdl.Diagnostics` contains several fields, such as `Leverage` and `CooksDistance`, that can help you identify particularly interesting observations.

This example shows how to examine a fitted nonlinear model using diagnostic, residual, and slice plots.

- 1 Load the reaction data.

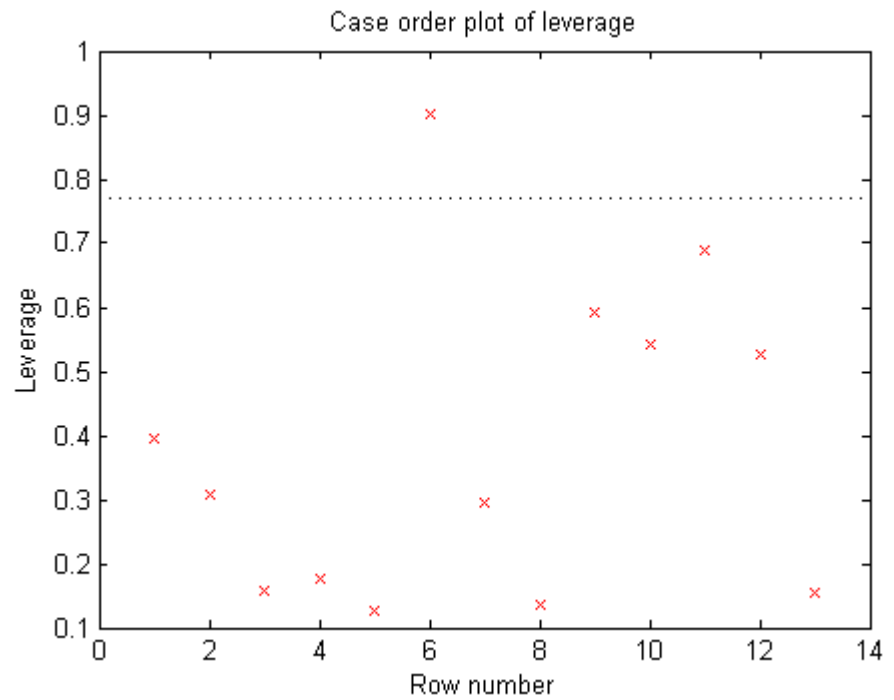
```
load reaction
```

- 2 Create a nonlinear model of `rate` as a function of `reactants` using the `hougen.m` function, starting from `beta0 = ones(5,1)`;

```
beta0 = ones(5,1);  
mdl = NonLinearModel.fit(reactants,...  
    rate,@hougen,beta0);
```

- 3 Make a leverage plot of the data and model.

```
plotDiagnostics(mdl)
```



4 There is one point that has high leverage. Locate the point:

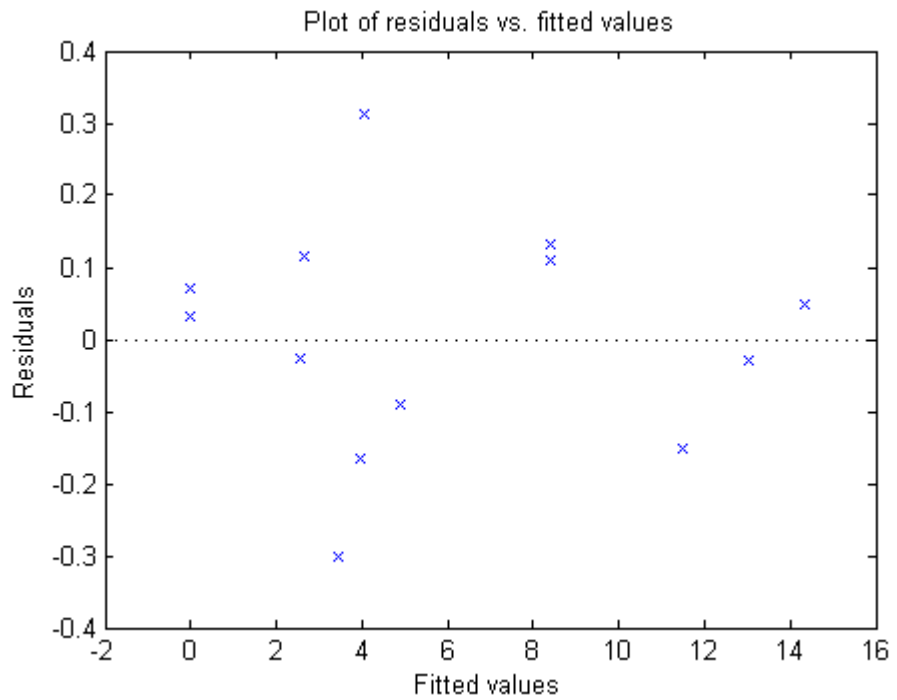
```
[~,max1] = max mdl.Diagnostics.Leverage)
```

```
max1 =
```

```
6
```

5 Examine a residuals plot.

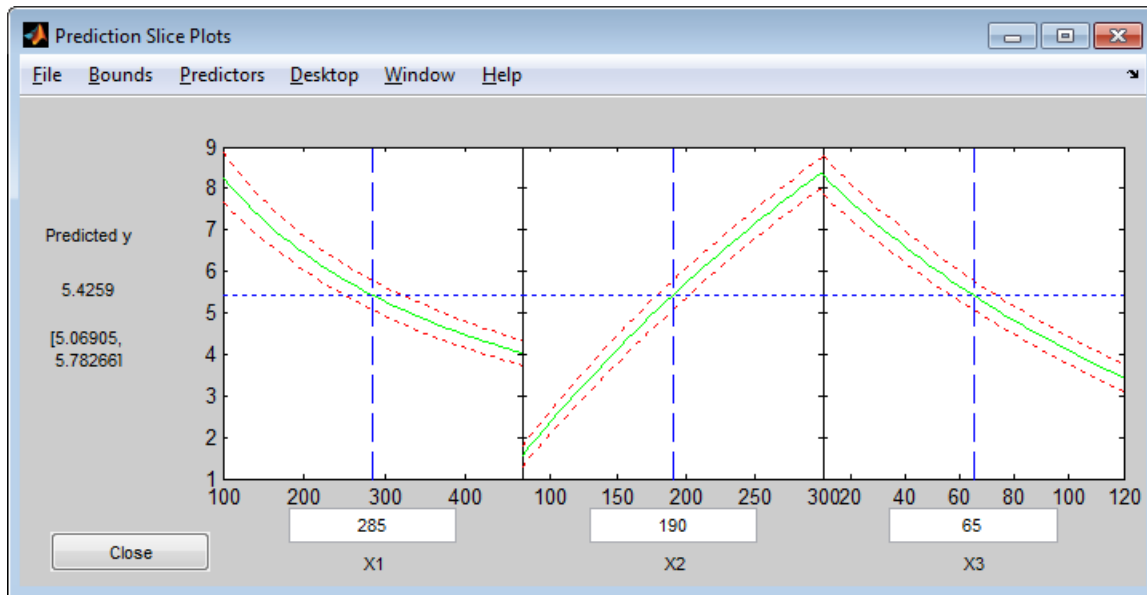
```
plotResiduals mdl, 'fitted')
```



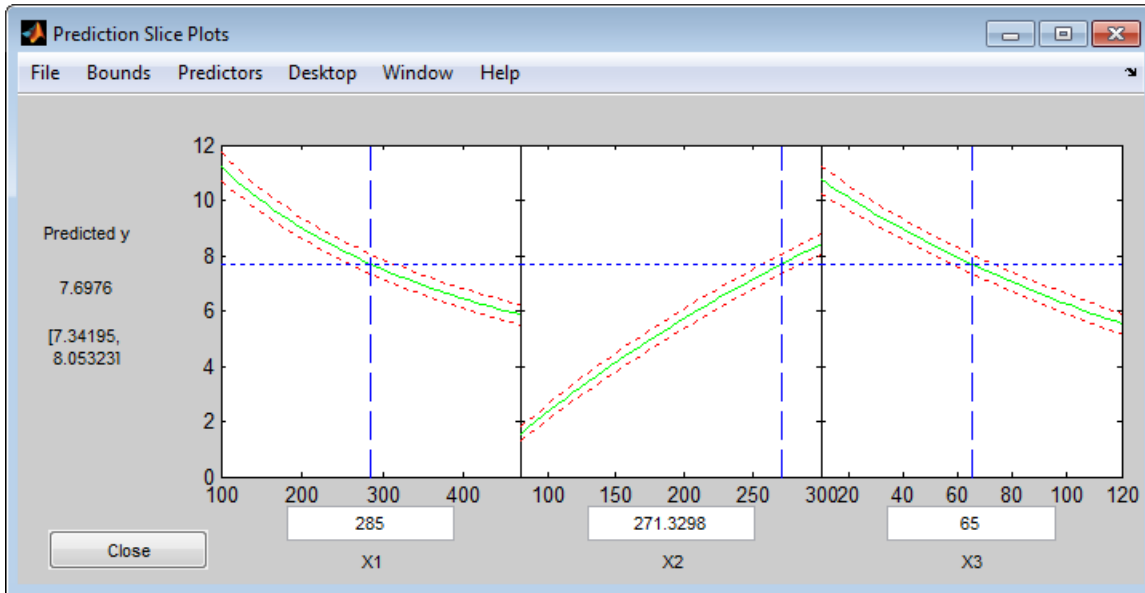
Nothing stands out as an outlier.

- 6 Use a slice plot to show the effect of each predictor on the model.

```
plotSlice mdl)
```



You can drag the vertical dashed blue lines to see the effect of a change in one predictor on the response. For example, drag the X2 line to the right, and notice that the slope of the X3 line changes.



Predict or Simulate Responses to New Data

There are three ways to use a linear model to predict or simulate the response to new data:

- “predict” on page 9-208
- “feval” on page 9-209
- “random” on page 9-209

The prediction method examples use the following synthetic data and model. The problem is to fit a nonlinear curve of known form, with unknown center and scale parameters.

- 1 Generate synthetic data from a Cauchy distribution.

```
rng('default')
X = rand(100,1);
X = tan(pi*X - pi/2);
```

- 2 Generate the response according to the model

$$y = b_1 * (\pi/2 + \text{atan}((x - b_2) / b_3)).$$

Add noise to the response.

```
modelfun = @(b,x) b(1) * ...
    (pi/2 + atan((x - b(2))/b(3)));
y = modelfun([12 5 10],X) + randn(100,1);
```

3 Fit a model starting from the arbitrary parameters $b = [1,1,1]$.

```
beta0 = [1 1 1]; % an arbitrary guess
mdl = NonLinearModel.fit(X,y,modelfun,beta0)
```

```
mdl =
```

```
Nonlinear regression model:
```

$$y \sim b_1 * (\pi/2 + \text{atan}((x - b_2) / b_3))$$

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
b1	12.082	0.80028	15.097	3.3151e-27
b2	5.0603	1.0825	4.6747	9.5063e-06
b3	9.64	0.46499	20.732	2.0382e-37

```
Number of observations: 100, Error degrees of freedom: 97
```

```
Root Mean Squared Error: 1.02
```

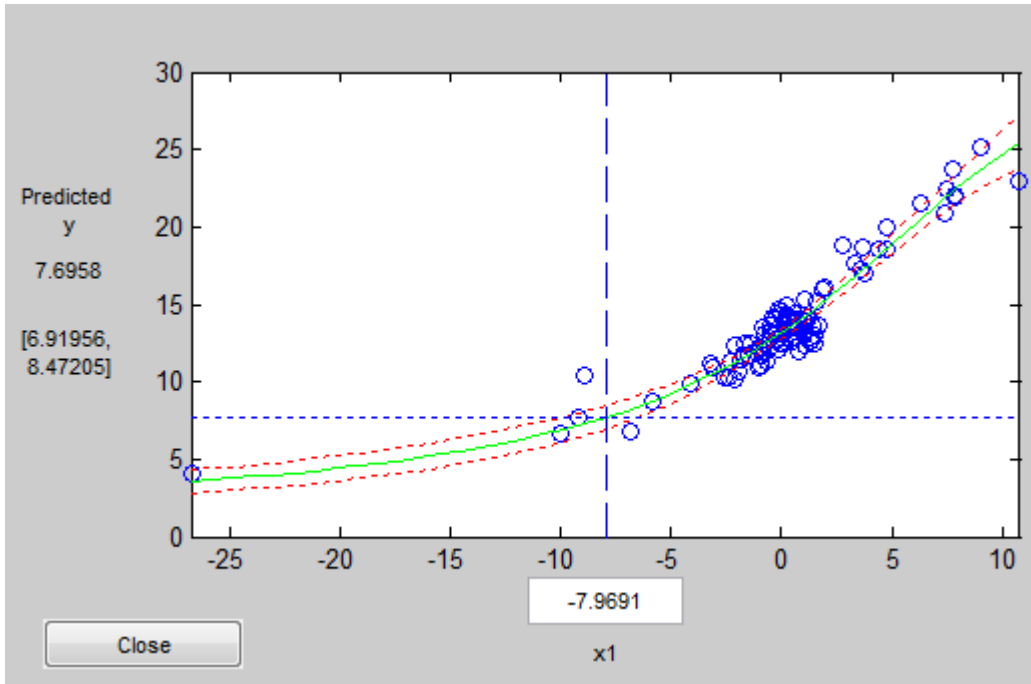
```
R-Squared: 0.92, Adjusted R-Squared 0.918
```

```
F-statistic vs. constant model: 558, p-value = 6.11e-54
```

The fitted values are within a few percent of the parameters [12,5,10].

4 Examine the fit:

```
plotSlice(mdl)
```



predict

The predict method predicts the mean responses and, if requested, gives confidence bounds. For example, to find the predicted response values and predicted confidence intervals about the response at X values [-15;5;12]:

```
Xnew = [-15;5;12];
[ynew,ynewci] = predict(md1,Xnew)
```

```
ynew =
```

```
5.4122
18.9022
26.5161
```

```
ynewci =
```



```

    4.8233    6.0010
    18.4555   19.3490
    25.0170   28.0151

```

The confidence intervals are reflected in the slice plot.

feval

The `feval` method predicts the mean responses. `feval` is often more convenient to use than `predict` when you construct a model from a dataset array. For example,

- 1 Create the nonlinear model from a dataset array.

```

ds = dataset({X,'X'},{y,'y'});
mdl2 = NonLinearModel.fit(ds,modelfun,beta0);

```

- 2 Find the predicted model responses (CDF) at X values [-15;5;12].

```

Xnew = [-15;5;12];
ynew = feval(mdl2,Xnew)

```

```

ynew =

    5.4122
   18.9022
   26.5161

```

random

The `random` method simulates new random response values, equal to the mean prediction plus a random disturbance with the same variance as the training data. For example,

```

Xnew = [-15;5;12];
ysim = random(mdl,Xnew)

```

```

ysim =

    6.0505
   19.0893
   25.4647

```

Rerun the random method. The results change.

```
ysim = random mdl, Xnew)
```

```
ysim =
```

```
6.3813
```

```
19.2157
```

```
26.6541
```

Nonlinear Regression Workflow

This example shows a typical workflow: import data, fit a nonlinear regression, test its quality, modify it to improve the quality, and make predictions based on the model.

Step 1. Prepare the data.

Load the reaction data

```
load reaction
```

Examine the data in the workspace. `reactants` is a matrix with 13 rows and 3 columns. Each row corresponds to one observation, and each column corresponds to one variable. The variable names are in `xn`:

```
xn
```

```
xn =
```

```
Hydrogen
```

```
n-Pentane
```

```
Isopentane
```

Similarly, `rate` is a vector of 13 responses, with the variable name in `yn`:

```
yn
```

```
yn =
```

```
Reaction Rate
```

The `hougen.m` file contains a nonlinear model of reaction rate as a function of the three predictor variables. For a 5-D vector b and 3-D vector x ,

$$\text{hougen}(b,x) = \frac{b(1)x(2) - x(3) / b(5)}{1 + b(2)x(1) + b(3)x(2) + b(4)x(3)}.$$

As a start point for the solution, take b as a vector of ones.

```
beta0 = ones(5,1);
```

Step 2. Fit a nonlinear model to the data.

```
mdl = NonLinearModel.fit(reactants,...
    rate,@hougen,beta0)
```

```
mdl =
```

```
Nonlinear regression model:
```

```
y ~ hougen(b,X)
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
b1	1.2526	0.86702	1.4447	0.18654
b2	0.062776	0.043562	1.4411	0.18753
b3	0.040048	0.030885	1.2967	0.23089
b4	0.11242	0.075158	1.4957	0.17309
b5	1.1914	0.83671	1.4239	0.1923

```
Number of observations: 13, Error degrees of freedom: 8
```

```
Root Mean Squared Error: 0.193
```

```
R-Squared: 0.999, Adjusted R-Squared 0.998
```

```
F-statistic vs. constant model: 1.81e+03, p-value = 7.36e-12
```

Step 3. Examine the quality of the model.

The root mean squared error is fairly low compared to the range of observed values.

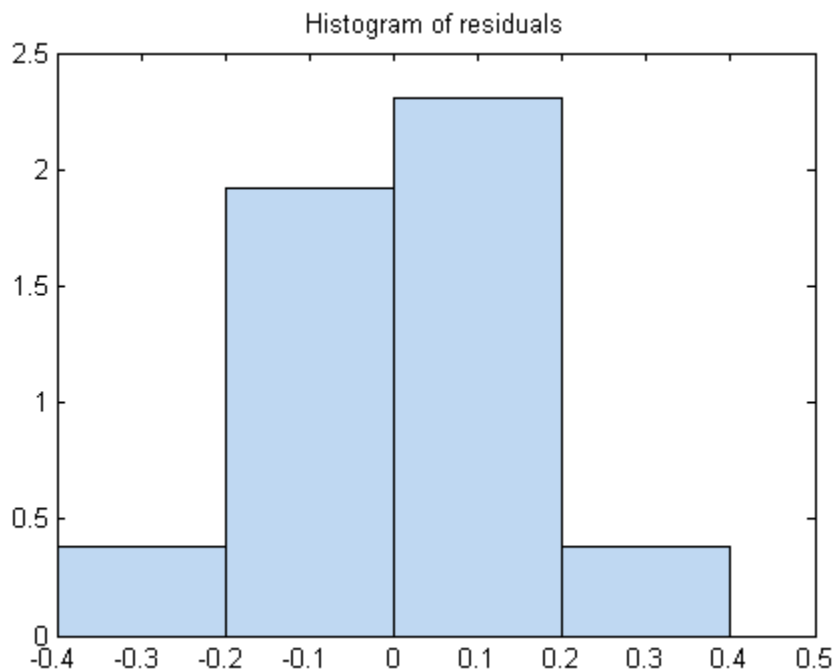
```
mdl.RMSE
```

```
ans =
```

```
0.1933  
[min(rate) max(rate)]  
ans =  
0.0200 14.3900
```

Examine a residuals plot.

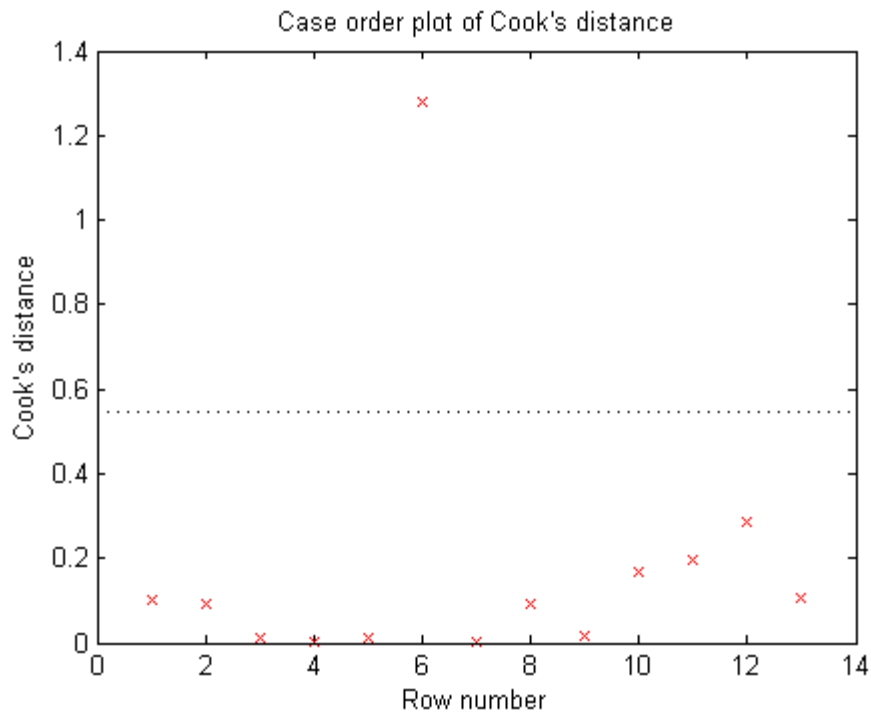
```
plotResiduals(md1)
```



The model seems adequate for the data.

Examine a diagnostic plot to look for outliers.

```
plotDiagnostics mdl, 'cookd')
```



Observation 6 seems out of line.

Step 4. Remove the outlier.

Remove the outlier from the fit using the Exclude name-value pair.

```
mdl1 = NonLinearModel.fit(reactants,...
    rate,@hougen,ones(5,1),'Exclude',6)
```

```
mdl1 =
```

```
Nonlinear regression model:
    y ~ hougen(b,X)
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
b1	0.619	0.4552	1.3598	0.21605
b2	0.030377	0.023061	1.3172	0.22924
b3	0.018927	0.01574	1.2024	0.26828
b4	0.053411	0.041084	1.3	0.23476
b5	2.4125	1.7903	1.3475	0.2198

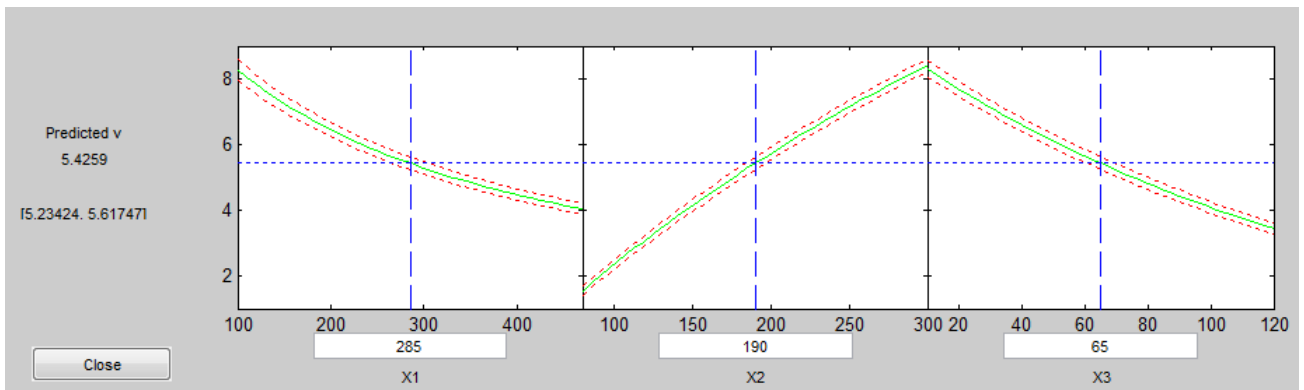
Number of observations: 12, Error degrees of freedom: 7
 Root Mean Squared Error: 0.198
 R-Squared: 0.999, Adjusted R-Squared 0.998
 F-statistic vs. constant model: 1.24e+03, p-value = 4.73e-10

The model coefficients changed quite a bit from those in mdl.

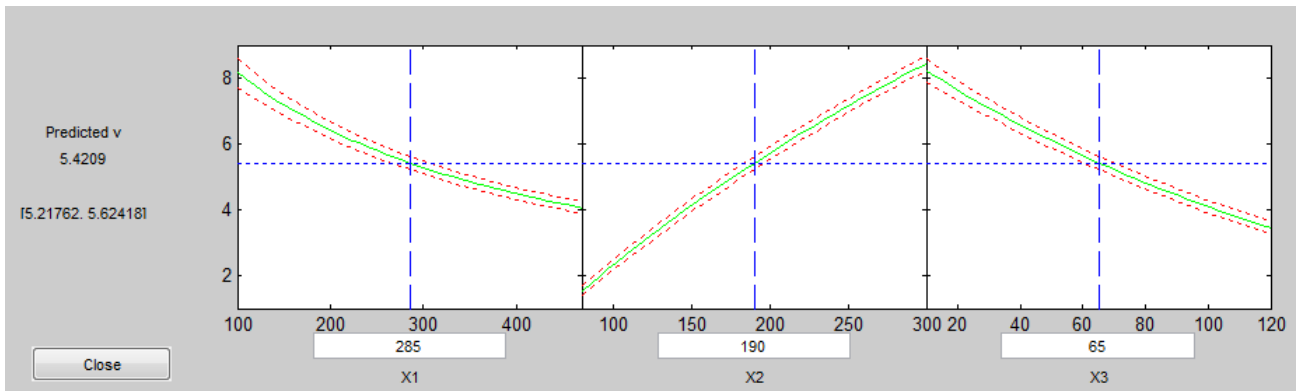
Step 5. Examine slice plots of both models.

To see the effect of each predictor on the response, make a slice plot using `plotSlice(mdl)`.

`plotSlice(mdl)`



`plotSlice(mdl1)`



The plots look very similar, with slightly wider confidence bounds for mdl1. This difference is understandable, since there is one less data point in the fit, representing over 7% fewer observations.

Step 6. Predict for new data.

Create some new data and predict the response from both models.

```
Xnew = [200,200,200;100,200,100;500,50,5];
[ypred yci] = predict mdl, Xnew
```

```
ypred =
```

```
1.8762
6.2793
1.6718
```

```
yci =
```

```
1.6283    2.1242
5.9789    6.5797
1.5589    1.7846
```

```
[ypred1 yci1] = predict mdl1, Xnew
```

```
ypred1 =
```

1.8984
6.2555
1.6594

yci1 =

1.6260 2.1708
5.9323 6.5787
1.5345 1.7843

Even though the model coefficients are dissimilar, the predictions are nearly identical.

Mixed-Effects Models

In this section...

“Introduction to Mixed-Effects Models” on page 9-217

“Mixed-Effects Model Hierarchy” on page 9-218

“Specifying Mixed-Effects Models” on page 9-219

“Specifying Covariate Models” on page 9-222

“Choosing nlmeFit or nlmeFitsa” on page 9-224

“Using Output Functions with Mixed-Effects Models” on page 9-227

“Mixed-Effects Models Using nlmeFit and nlmeFitsa” on page 9-232

“Examining Residuals for Model Verification” on page 9-247

Introduction to Mixed-Effects Models

In statistics, an *effect* is anything that influences the value of a response variable at a particular setting of the predictor variables. Effects are translated into model parameters. In linear models, effects become coefficients, representing the proportional contributions of model terms. In nonlinear models, effects often have specific physical interpretations, and appear in more general nonlinear combinations.

Fixed effects represent population parameters, assumed to be the same each time data is collected. Estimating fixed effects is the traditional domain of regression modeling. *Random effects*, by comparison, are sample-dependent random variables. In modeling, random effects act like additional error terms, and their distributions and covariances must be specified.

For example, consider a model of the elimination of a drug from the bloodstream. The model uses time t as a predictor and the concentration of the drug C as the response. The nonlinear model term $C_0 e^{-rt}$ combines parameters C_0 and r , representing, respectively, an initial concentration and an elimination rate. If data is collected across multiple individuals, it is reasonable to assume that the elimination rate is a random variable r_i depending on individual i , varying around a population mean \bar{r} . The term $C_0 e^{-rt}$ becomes

$$C_0 e^{-[\bar{r} + (r_i - \bar{r})]t} = C_0 e^{-(\beta + b_i)t},$$

where $\beta = \bar{r}$ is a fixed effect and $b_i = r_i - \bar{r}$ is a random effect.

Random effects are useful when data falls into natural groups. In the drug elimination model, the groups are simply the individuals under study. More sophisticated models might group data by an individual's age, weight, diet, etc. Although the groups are not the focus of the study, adding random effects to a model extends the reliability of inferences beyond the specific sample of individuals.

Mixed-effects models account for both fixed and random effects. As with all regression models, their purpose is to describe a response variable as a function of the predictor variables. Mixed-effects models, however, recognize correlations within sample subgroups. In this way, they provide a compromise between ignoring data groups entirely and fitting each group with a separate model.

Mixed-Effects Model Hierarchy

Suppose data for a nonlinear regression model falls into one of m distinct groups $i = 1, \dots, m$. To account for the groups in a model, write response j in group i as:

$$y_{ij} = f(\varphi, x_{ij}) + \varepsilon_{ij}$$

y_{ij} is the response, x_{ij} is a vector of predictors, φ is a vector of model parameters, and ε_{ij} is the measurement or process error. The index j ranges from 1 to n_i , where n_i is the number of observations in group i . The function f specifies the form of the model. Often, x_{ij} is simply an observation time t_{ij} . The errors are usually assumed to be independent and identically, normally distributed, with constant variance.

Estimates of the parameters in φ describe the population, assuming those estimates are the same for all groups. If, however, the estimates vary by group, the model becomes

$$y_{ij} = f(\varphi_i, x_{ij}) + \varepsilon_{ij}$$

In a mixed-effects model, φ_i may be a combination of a fixed and a random effect:

$$\varphi_i = \beta + b_i$$

The random effects b_i are usually described as multivariate normally distributed, with mean zero and covariance Ψ . Estimating the fixed effects β and the covariance of the random effects Ψ provides a description of the population that does not assume the parameters φ_i are the same across groups. Estimating the random effects b_i also gives a description of specific groups within the data.

Model parameters do not have to be identified with individual effects. In general, *design matrices* A and B are used to identify parameters with linear combinations of fixed and random effects:

$$\varphi_i = A\beta + Bb_i$$

If the design matrices differ among groups, the model becomes

$$\varphi_i = A_i\beta + B_i b_i$$

If the design matrices also differ among observations, the model becomes

$$\begin{aligned}\varphi_{ij} &= A_{ij}\beta + B_{ij}b_i \\ y_{ij} &= f(\varphi_{ij}, x_{ij}) + \varepsilon_{ij}\end{aligned}$$

Some of the group-specific predictors in x_{ij} may not change with observation j . Calling those v_i , the model becomes

$$y_{ij} = f(\varphi_{ij}, x_{ij}, v_i) + \varepsilon_{ij}$$

Specifying Mixed-Effects Models

Suppose data for a nonlinear regression model falls into one of m distinct groups $i = 1, \dots, m$. (Specifically, suppose that the groups are not nested.) To specify a general nonlinear mixed-effects model for this data:

- 1 Define group-specific model parameters φ_i as linear combinations of fixed effects β and random effects b_i .
- 2 Define response values y_i as a nonlinear function f of the parameters and group-specific predictor variables X_i .

The model is:

$$\begin{aligned}\varphi_i &= A_i\beta + B_ib_i \\ y_i &= f(\varphi_i, X_i) + \varepsilon_i \\ b_i &\square N(0, \Psi) \\ \varepsilon_i &\square N(0, \sigma^2)\end{aligned}$$

This formulation of the nonlinear mixed-effects model uses the following notation:

φ_i	A vector of group-specific model parameters
β	A vector of fixed effects, modeling population parameters
b_i	A vector of multivariate normally distributed group-specific random effects
A_i	A group-specific design matrix for combining fixed effects
B_i	A group-specific design matrix for combining random effects
X_i	A data matrix of group-specific predictor values
y_i	A data vector of group-specific response values
f	A general, real-valued function of φ_i and X_i
ε_i	A vector of group-specific errors, assumed to be independent, identically, normally distributed, and independent of b_i
Ψ	A covariance matrix for the random effects
σ^2	The error variance, assumed to be constant across observations

For example, consider a model of the elimination of a drug from the bloodstream. The model incorporates two overlapping phases:

- An initial phase p during which drug concentrations reach equilibrium with surrounding tissues
- A second phase q during which the drug is eliminated from the bloodstream

For data on multiple individuals i , the model is

$$y_{ij} = C_{pi}e^{-r_{pi}t_{ij}} + C_{qi}e^{-r_{qi}t_{ij}} + \varepsilon_{ij},$$

where y_{ij} is the observed concentration in individual i at time t_{ij} . The model allows for different sampling times and different numbers of observations for different individuals.

The elimination rates r_{pi} and r_{qi} must be positive to be physically meaningful. Enforce this by introducing the log rates $R_{pi} = \log(r_{pi})$ and $R_{qi} = \log(r_{qi})$ and reparametrizing the model:

$$y_{ij} = C_{pi}e^{-\exp(R_{pi})t_{ij}} + C_{qi}e^{-\exp(R_{qi})t_{ij}} + \varepsilon_{ij}$$

Choosing which parameters to model with random effects is an important consideration when building a mixed-effects model. One technique is to add random effects to all parameters, and use estimates of their variances to determine their significance in the model. An alternative is to fit the model separately to each group, without random effects, and look at the variation of the parameter estimates. If an estimate varies widely across groups, or if confidence intervals for each group have minimal overlap, the parameter is a good candidate for a random effect.

To introduce fixed effects β and random effects b_i for all model parameters, reexpress the model as follows:

$$\begin{aligned} y_{ij} &= [\bar{C}_p + (C_{pi} - \bar{C}_p)]e^{-\exp[\bar{R}_p + (R_{pi} - \bar{R}_p)]t_{ij}} + \\ &\quad [\bar{C}_q + (C_{qi} - \bar{C}_q)]e^{-\exp[\bar{R}_q + (R_{qi} - \bar{R}_q)]t_{ij}} + \varepsilon_{ij} \\ &= (\beta_1 + b_{1i})e^{-\exp(\beta_2 + b_{2i})t_{ij}} + \\ &\quad (\beta_3 + b_{3i})e^{-\exp(\beta_4 + b_{4i})t_{ij}} + \varepsilon_{ij} \end{aligned}$$

In the notation of the general model:

$$\beta = \begin{pmatrix} \beta_1 \\ \vdots \\ \beta_4 \end{pmatrix}, b_i = \begin{pmatrix} b_{i1} \\ \vdots \\ b_{i4} \end{pmatrix}, y_i = \begin{pmatrix} y_{i1} \\ \vdots \\ y_{in_i} \end{pmatrix}, X_i = \begin{pmatrix} t_{i1} \\ \vdots \\ t_{in_i} \end{pmatrix},$$

where n_i is the number of observations of individual i . In this case, the design matrices A_i and B_i are, at least initially, 4-by-4 identity matrices. Design matrices may be altered, as necessary, to introduce weighting of individual effects, or time dependency.

Fitting the model and estimating the covariance matrix Ψ often leads to further refinements. A relatively small estimate for the variance of a random effect suggests that it can be removed from the model. Likewise, relatively small estimates for covariances among certain random effects suggests that a full covariance matrix is unnecessary. Since random effects are unobserved, Ψ must be estimated indirectly. Specifying a diagonal or block-diagonal covariance pattern for Ψ can improve convergence and efficiency of the fitting algorithm.

Statistics Toolbox functions `nlmefit` and `nlmefitsa` fit the general nonlinear mixed-effects model to data, estimating the fixed and random effects. The functions also estimate the covariance matrix Ψ for the random effects. Additional diagnostic outputs allow you to assess tradeoffs between the number of model parameters and the goodness of fit.

Specifying Covariate Models

If the model in “Specifying Mixed-Effects Models” on page 9-219 assumes a group-dependent covariate such as weight (w) the model becomes:

$$\begin{pmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & w_i \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \end{pmatrix} + \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} b_1 \\ b_2 \\ b_3 \end{pmatrix}$$

Thus, the parameter φ_i for any individual in the i th group is:

$$\begin{pmatrix} \varphi_{1_i} \\ \varphi_{2_i} \\ \varphi_{3_i} \end{pmatrix} = \begin{pmatrix} \beta_1 + \beta_4 * w_i \\ \beta_2 \\ \beta_3 \end{pmatrix} + \begin{pmatrix} b_{1_i} \\ b_{2_i} \\ b_{3_i} \end{pmatrix}$$

To specify a covariate model, use the 'FEGroupDesign' option.

'FEGroupDesign' is a p-by-q-by-m array specifying a different p-by-q fixed-effects design matrix for each of the m groups. Using the previous example, the array resembles the following:

$$\begin{bmatrix} \begin{bmatrix} 1 & 0 & 0 & W_1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} & \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \\ \begin{bmatrix} 1 & 0 & 0 & W_2 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} & \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \\ \begin{bmatrix} 1 & 0 & 0 & W_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} & \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \\ \dots & \dots \\ \begin{bmatrix} 1 & 0 & 0 & W_m \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} & \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \end{bmatrix}$$

1 Create the array.

```
% Number of parameters in the model (Phi)
num_params = 3;
% Number of covariates
num_cov = 1;
% Assuming number of groups in the data set is 7
num_groups = 7;
% Array of covariate values
covariates = [75; 52; 66; 55; 70; 58; 62 ];
A = repmat(eye(num_params, num_params+num_cov), ...
[1,1,num_groups]);
A(1,num_params+1,1:num_groups) = covariates(:,1)
```

2 Create a struct with the specified design matrix.

```
options.FEGroupDesign = A;
```

- 3 Specify the arguments for `nlmefit` (or `nlmefitsa`) as shown in “Mixed-Effects Models Using `nlmefit` and `nlmefitsa`” on page 9-232.

Choosing `nlmefit` or `nlmefitsa`

Statistics Toolbox provides two functions, `nlmefit` and `nlmefitsa` for fitting nonlinear mixed-effects models. Each function provides different capabilities, which may help you decide which to use.

- “Approximation Methods” on page 9-224
- “Parameters Specific to `nlmefitsa`” on page 9-225
- “Model and Data Requirements” on page 9-226

Approximation Methods

`nlmefit` provides the following four approximation methods for fitting nonlinear mixed-effects models:

- 'LME' — Use the likelihood for the linear mixed-effects model at the current conditional estimates of `beta` and `B`. This is the default.
- 'RELME' — Use the restricted likelihood for the linear mixed-effects model at the current conditional estimates of `beta` and `B`.
- 'FO' — First-order Laplacian approximation without random effects.
- 'FOCE' — First-order Laplacian approximation at the conditional estimates of `B`.

`nlmefitsa` provides an additional approximation method, Stochastic Approximation Expectation-Maximization (SAEM) [24] with three steps :

- 1 Simulation: Generate simulated values of the random effects b from the posterior density $p(b | \Sigma)$ given the current parameter estimates.
- 2 Stochastic approximation: Update the expected value of the log likelihood function by taking its value from the previous step, and moving part way toward the average value of the log likelihood calculated from the simulated random effects.

- 3 Maximization step: Choose new parameter estimates to maximize the log likelihood function given the simulated values of the random effects.

Both `nlmefit` and `nlmefitsa` attempt to find parameter estimates to maximize a likelihood function, which is difficult to compute. `nlmefit` deals with the problem by approximating the likelihood function in various ways, and maximizing the approximate function. It uses traditional optimization techniques that depend on things like convergence criteria and iteration limits.

`nlmefitsa`, on the other hand, simulates random values of the parameters in such a way that in the long run they converge to the values that maximize the exact likelihood function. The results are random, and traditional convergence tests don't apply. Therefore `nlmefitsa` provides options to plot the results as the simulation progresses, and to restart the simulation multiple times. You can use these features to judge whether the results have converged to the accuracy you desire.

Parameters Specific to `nlmefitsa`

The following parameters are specific to `nlmefitsa`. Most control the stochastic algorithm.

- `Cov0` — Initial value for the covariance matrix `PSI`. Must be an r -by- r positive definite matrix. If empty, the default value depends on the values of `BETA0`.
- `ComputeStdErrors` — `true` to compute standard errors for the coefficient estimates and store them in the output `STATS` structure, or `false` (default) to omit this computation.
- `LogLikMethod` — Specifies the method for approximating the log likelihood.
- `NBurnIn` — Number of initial burn-in iterations during which the parameter estimates are not recomputed. Default is 5.
- `NIterations` — Controls how many iterations are performed for each of three phases of the algorithm.
- `NMCMCIterations` — Number of Markov Chain Monte Carlo (MCMC) iterations.

Model and Data Requirements

There are some differences in the capabilities of `nlmefit` and `nlmefitsa`. Therefore some data and models are usable with either function, but some may require you to choose just one of them.

- **Error models** — `nlmefitsa` supports a variety of error models. For example, the standard deviation of the response can be constant, proportional to the function value, or a combination of the two. `nlmefit` fits models under the assumption that the standard deviation of the response is constant. One of the error models, 'exponential', specifies that the log of the response has a constant standard deviation. You can fit such models using `nlmefit` by providing the log response as input, and by rewriting the model function to produce the log of the nonlinear function value.
- **Random effects** — Both functions fit data to a nonlinear function with parameters, and the parameters may be simple scalar values or linear functions of covariates. `nlmefit` allows any coefficients of the linear functions to have both fixed and random effects. `nlmefitsa` supports random effects only for the constant (intercept) coefficient of the linear functions, but not for slope coefficients. So in the example in “Specifying Covariate Models” on page 9-222, `nlmefitsa` can treat only the first three beta values as random effects.
- **Model form** — `nlmefit` supports a very general model specification, with few restrictions on the design matrices that relate the fixed coefficients and the random effects to the model parameters. `nlmefitsa` is more restrictive:
 - The fixed effect design must be constant in every group (for every individual), so an observation-dependent design is not supported.
 - The random effect design must be constant for the entire data set, so neither an observation-dependent design nor a group-dependent design is supported.
 - As mentioned under **Random Effects**, the random effect design must not specify random effects for slope coefficients. This implies that the design must consist of zeros and ones.
 - The random effect design must not use the same random effect for multiple coefficients, and cannot use more than one random effect for any single coefficient.

- The fixed effect design must not use the same coefficient for multiple parameters. This implies that it can have at most one nonzero value in each column.

If you want to use `nlmefitsa` for data in which the covariate effects are random, include the covariates directly in the nonlinear model expression. Don't include the covariates in the fixed or random effect design matrices.

- **Convergence** — As described in the **Model form**, `nlmefit` and `nlmefitsa` have different approaches to measuring convergence. `nlmefit` uses traditional optimization measures, and `nlmefitsa` provides diagnostics to help you judge the convergence of a random simulation.

In practice, `nlmefitsa` tends to be more robust, and less likely to fail on difficult problems. However, `nlmefit` may converge faster on problems where it converges at all. Some problems may benefit from a combined strategy, for example by running `nlmefitsa` for a while to get reasonable parameter estimates, and using those as a starting point for additional iterations using `nlmefit`.

Using Output Functions with Mixed-Effects Models

The `OutputFcn` field of the options structure specifies one or more functions that the solver calls after each iteration. Typically, you might use an output function to plot points at each iteration or to display optimization quantities from the algorithm. To set up an output function:

- 1 Write the output function as a MATLAB file function or local function.
- 2 Use `statset` to set the value of `OutputFcn` to be a function handle, that is, the name of the function preceded by the `@` sign. For example, if the output function is `outfun.m`, the command

```
options = statset('OutputFcn', @outfun);
```

specifies `OutputFcn` to be the handle to `outfun`. To specify multiple output functions, use the syntax:

```
options = statset('OutputFcn',{@outfun, @outfun2});
```

- 3 Call the optimization function with options as an input argument.

For an example of an output function, see “Sample Output Function” on page 9-232.

Structure of the Output Function

The function definition line of the output function has the following form:

```
stop = outfun(beta,status,state)
```

where

- *beta* is the current fixed effects.
- *status* is a structure containing data from the current iteration. “Fields in status” on page 9-228 describes the structure in detail.
- *state* is the current state of the algorithm. “States of the Algorithm” on page 9-229 lists the possible values.
- *stop* is a flag that is true or false depending on whether the optimization routine should quit or continue. See “Stop Flag” on page 9-230 for more information.

The solver passes the values of the input arguments to `outfun` at each iteration.

Fields in status

The following table lists the fields of the `status` structure:

Field	Description
procedure	<ul style="list-style-type: none"> • 'ALT' — alternating algorithm for the optimization of the linear mixed effects or restricted linear mixed effects approximations • 'LAP' — optimization of the Laplacian approximation for first order or first order conditional estimation
iteration	An integer starting from 0.

Field	Description
inner	<p>A structure describing the status of the inner iterations within the ALT and LAP procedures, with the fields:</p> <ul style="list-style-type: none"> • procedure — When procedure is 'ALT': <ul style="list-style-type: none"> ▪ 'PNLS' (penalized nonlinear least squares) ▪ 'LME' (linear mixed-effects estimation) ▪ 'none' When procedure is 'LAP', <ul style="list-style-type: none"> ▪ 'PNLS' (penalized nonlinear least squares) ▪ 'PLM' (profiled likelihood maximization) ▪ 'none' • state — one of the following: <ul style="list-style-type: none"> ▪ 'init' ▪ 'iter' ▪ 'done' ▪ 'none' • iteration — an integer starting from 0, or NaN. For <code>nlmefitsa</code> with burn-in iterations, the output function is called after each of those iterations with a negative value for <code>STATUS.iteration</code>.
fval	The current log likelihood
Psi	The current random-effects covariance matrix
theta	The current parameterization of Psi
mse	The current error variance

States of the Algorithm

The following table lists the possible values for state:

state	Description
'init'	The algorithm is in the initial state before the first iteration.
'iter'	The algorithm is at the end of an iteration.
'done'	The algorithm is in the final state after the last iteration.

The following code illustrates how the output function might use the value of `state` to decide which tasks to perform at the current iteration:

```
switch state
    case 'iter'
        % Make updates to plot or guis as needed
    case 'init'
        % Setup for plots or guis
    case 'done'
        % Cleanup of plots, guis, or final plot
otherwise
end
```

Stop Flag

The output argument `stop` is a flag that is true or false. The flag tells the solver whether it should quit or continue. The following examples show typical ways to use the stop flag.

Stopping an Optimization Based on Intermediate Results. The output function can stop the estimation at any iteration based on the values of arguments passed into it. For example, the following code sets `stop` to true based on the value of the log likelihood stored in the `'fval'` field of the status structure:

```
stop = outfun(beta,status,state)
stop = false;
% Check if loglikelihood is more than 132.
if status.fval > -132
    stop = true;
end
```

Stopping an Iteration Based on GUI Input. If you design a GUI to perform `nlmefit` iterations, you can make the output function stop when a user clicks a **Stop** button on the GUI. For example, the following code implements a dialog to cancel calculations:

```
function retval = stop_outfcn(beta,str,status)
persistent h stop;
if isequal(str.inner.state,'none')
    switch(status)
        case 'init'
            % Initialize dialog
            stop = false;
            h = msgbox('Press STOP to cancel calculations.',...
                'NLMEFIT: Iteration 0 ');
            button = findobj(h,'type','uicontrol');
            set(button,'String','STOP','Callback',@stopper)
            pos = get(h,'Position');
            pos(3) = 1.1 * pos(3);
            set(h,'Position',pos)
            drawnow
        case 'iter'
            % Display iteration number in the dialog title
            set(h,'Name',sprintf('NLMEFIT: Iteration %d',...
                str.iteration))
            drawnow;
        case 'done'
            % Delete dialog
            delete(h);
    end
end
if stop
    % Stop if the dialog button has been pressed
    delete(h)
end
retval = stop;

function stopper(varargin)
    % Set flag to stop when button is pressed
    stop = true;
    disp('Calculation stopped.')
```

```
        end  
    end
```

Sample Output Function

`nlmefitoutputfcn` is the sample Statistics Toolbox output function for `nlmefit` and `nlmefitsa`. It initializes or updates a plot with the fixed-effects (BETA) and variance of the random effects (`diag(STATUS.Psi)`). For `nlmefit`, the plot also includes the log-likelihood (`STATUS.fval`).

`nlmefitoutputfcn` is the default output function for `nlmefitsa`. To use it with `nlmefit`, specify a function handle for it in the options structure:

```
opt = statset('OutputFcn', @nlmefitoutputfcn, )  
beta = nlmefit( , 'Options', opt, )
```

To prevent `nlmefitsa` from using of this function, specify an empty value for the output function:

```
opt = statset('OutputFcn', [], )  
beta = nlmefitsa( , 'Options', opt, )
```

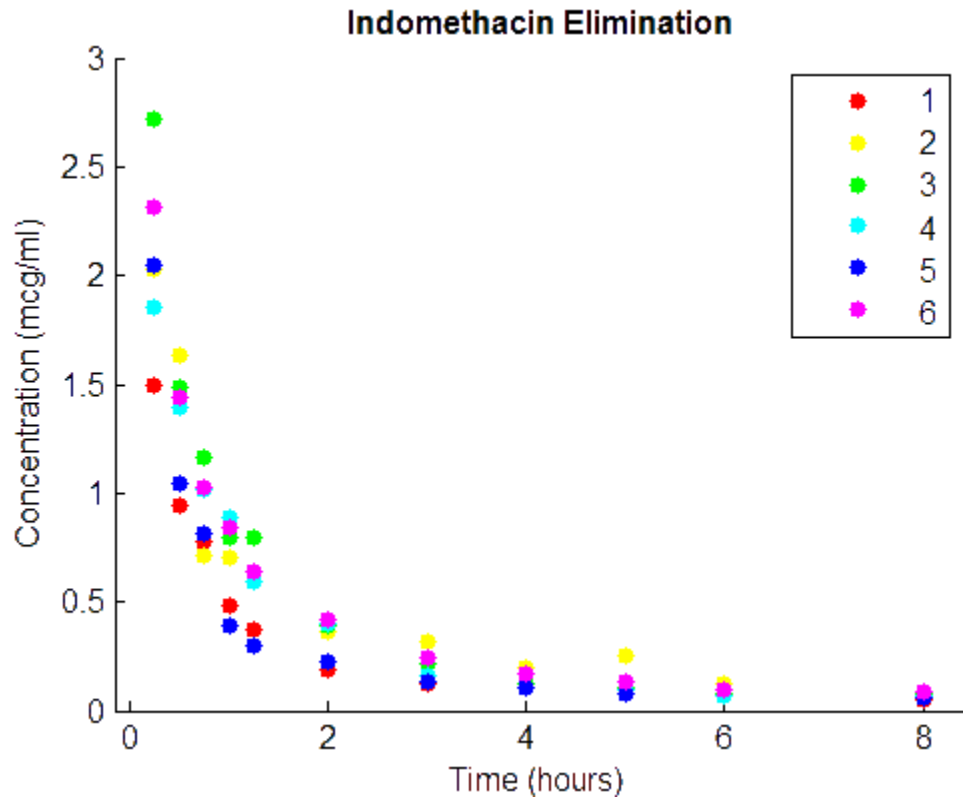
`nlmefitoutputfcn` stops `nlmefit` or `nlmefitsa` if you close the figure that it produces.

Mixed-Effects Models Using `nlmefit` and `nlmefitsa`

The following example also works with `nlmefitsa` in place of `nlmefit`.

The data in `indomethacin.mat` records concentrations of the drug indomethacin in the bloodstream of six subjects over eight hours:

```
load indomethacin  
  
gscatter(time,concentration,subject)  
xlabel('Time (hours)')  
ylabel('Concentration (mcg/ml)')  
title('{\bf Indomethacin Elimination}')  
hold on
```

“Specifying Mixed-Effects Models” on page 9-219 discusses a useful model for this type of data. Construct the model via an anonymous function as follows:

```
model = @(phi,t)(phi(1)*exp(-exp(phi(2))*t) + ...
             phi(3)*exp(-exp(phi(4))*t));
```

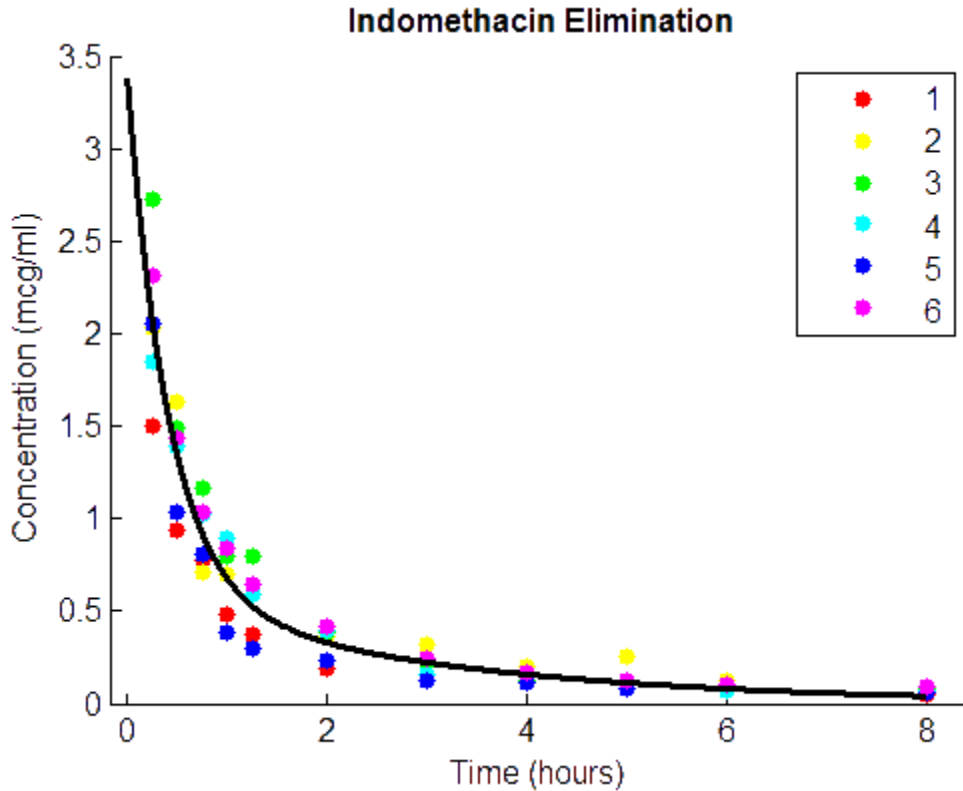
Use the `nlinfit` function to fit the model to all of the data, ignoring subject-specific effects:

```
phi0 = [1 2 1 1];
[phi,res] = nlinfit(time,concentration,model,phi0);
```

```
numObs = length(time);
numParams = 4;
df = numObs-numParams;
mse = (res'*res)/df
```

```
mse =
    0.0304

tplot = 0:0.01:8;
plot(tplot,model(phi,tplot),'k','LineWidth',2)
hold off
```



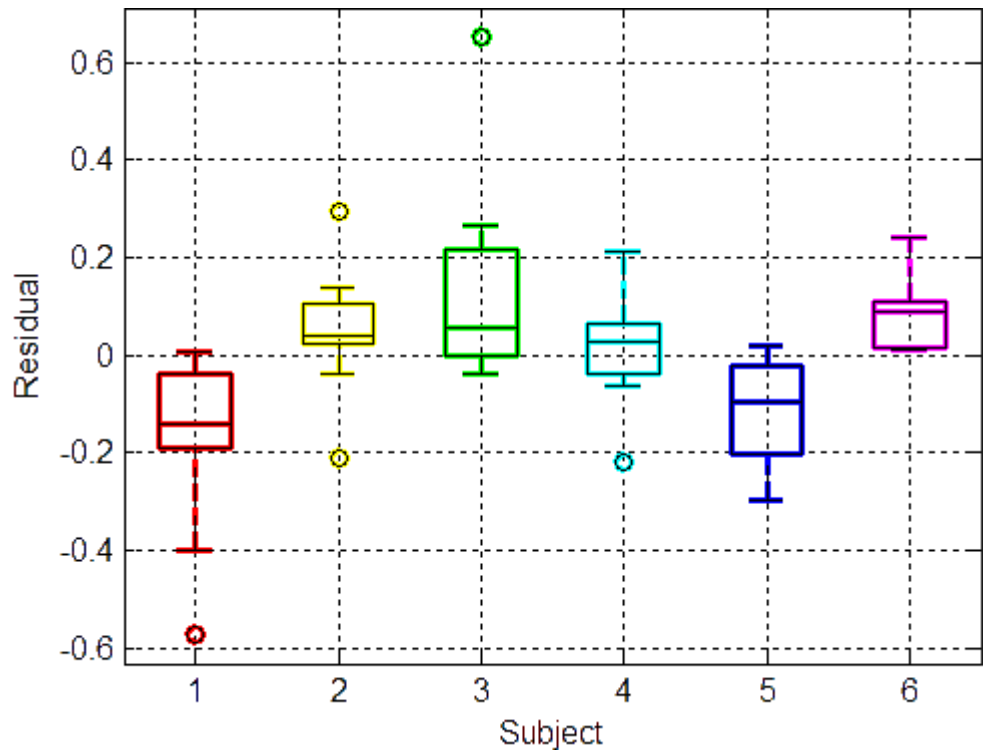
A box plot of residuals by subject shows that the boxes are mostly above or below zero, indicating that the model has failed to account for subject-specific effects:

```
colors = 'rygcbm';
h = boxplot(res,subject,'colors',colors,'symbol','o');
set(h(~isnan(h)),'LineWidth',2)
hold on
boxplot(res,subject,'colors','k','symbol','ko')
```

```

grid on
xlabel('Subject')
ylabel('Residual')
hold off

```



To account for subject-specific effects, fit the model separately to the data for each subject:

```

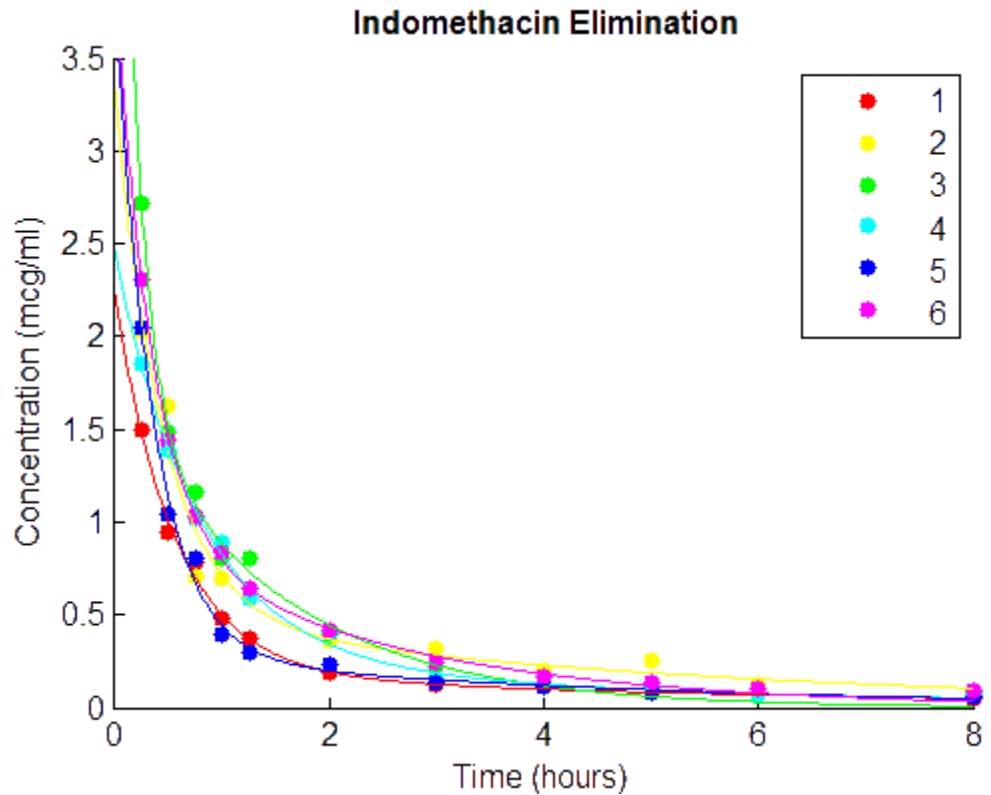
phi0 = [1 2 1 1];
PHI = zeros(4,6);
RES = zeros(11,6);
for I = 1:6
    tI = time(subject == I);
    cI = concentration(subject == I);
    [PHI(:,I),RES(:,I)] = nlinfit(tI,cI,model,phi0);
end

```

```
PHI
PHI =
    2.0293    2.8277    5.4683    2.1981    3.5661    3.0023
    0.5794    0.8013    1.7498    0.2423    1.0408    1.0882
    0.1915    0.4989    1.6757    0.2545    0.2915    0.9685
   -1.7878   -1.6354   -0.4122   -1.6026   -1.5069   -0.8731
```

```
numParams = 24;
df = numObs-numParams;
mse = (RES(:)'*RES(:))/df
mse =
    0.0057
```

```
gscatter(time,concentration,subject)
xlabel('Time (hours)')
ylabel('Concentration (mcg/ml)')
title('\bf Indomethacin Elimination')
hold on
for I = 1:6
    plot(tplot,model(PHI(:,I),tplot),'Color',colors(I))
end
axis([0 8 0 3.5])
hold off
```

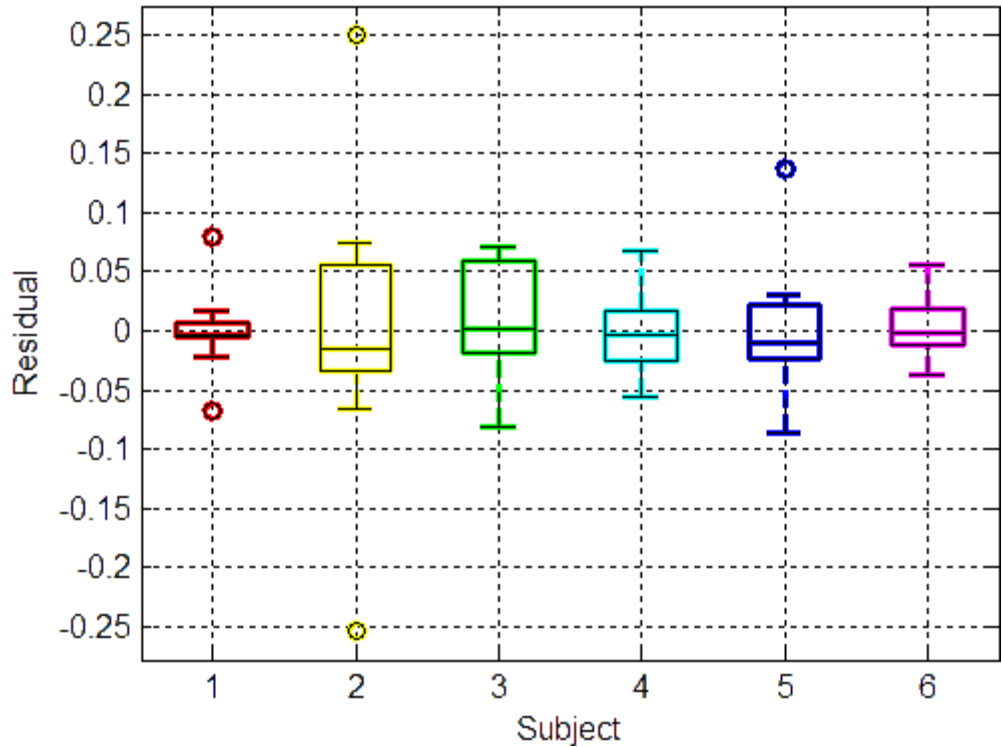


PHI gives estimates of the four model parameters for each of the six subjects. The estimates vary considerably, but taken as a 24-parameter model of the data, the mean-squared error of 0.0057 is a significant reduction from 0.0304 in the original four-parameter model.

A box plot of residuals by subject shows that the larger model accounts for most of the subject-specific effects:

```
h = boxplot(RES, 'colors', colors, 'symbol', 'o');
set(h(~isnan(h)), 'LineWidth', 2)
hold on
boxplot(RES, 'colors', 'k', 'symbol', 'ko')
grid on
xlabel('Subject')
ylabel('Residual')
```

hold off



The spread of the residuals (the vertical scale of the box plot) is much smaller than in the previous box plot, and the boxes are now mostly centered on zero.

While the 24-parameter model successfully accounts for variations due to the specific subjects in the study, it does not consider the subjects as representatives of a larger population. The sampling distribution from which the subjects are drawn is likely more interesting than the sample itself. The purpose of mixed-effects models is to account for subject-specific variations more broadly, as random effects varying around population means.

Use the `nlmefit` function to fit a mixed-effects model to the data.

The following anonymous function, `nlme_model`, adapts the four-parameter model used by `nlinf` to the calling syntax of `nlmefit` by allowing separate

parameters for each individual. By default, `nlmefit` assigns random effects to all the model parameters. Also by default, `nlmefit` assumes a diagonal covariance matrix (no covariance among the random effects) to avoid overparametrization and related convergence issues.

```
nlme_model = @(PHI,t)(PHI(:,1).*exp(-exp(PHI(:,2)).*t) + ...
                    PHI(:,3).*exp(-exp(PHI(:,4)).*t));
```

```
phi0 = [1 2 1 1];
[phi,PSI,stats] = nlmefit(time,concentration,subject, ...
                        [],nlme_model,phi0)
```

```
phi =
    2.8277
    0.7729
    0.4606
   -1.3459
```

```
PSI =
    0.3264         0         0         0
         0    0.0250         0         0
         0         0    0.0124         0
         0         0         0    0.0000
```

```
stats =
    dfe: 57
    logl: 54.5882
    mse: 0.0066
    rmse: 0.0787
    errorparam: 0.0815
    aic: -91.1765
    bic: -93.0506
    covb: [4x4 double]
    sebeta: [0.2558 0.1066 0.1092 0.2244]
    ires: [66x1 double]
    pres: [66x1 double]
    iwres: [66x1 double]
    pwres: [66x1 double]
    cwres: [66x1 double]
```

The mean-squared error of 0.0066 is comparable to the 0.0057 of the 24-parameter model without random effects, and significantly better than the 0.0304 of the four-parameter model without random effects.

The estimated covariance matrix PSI shows that the variance of the fourth random effect is essentially zero, suggesting that you can remove it to simplify the model. To do this, use the REParamsSelect parameter to specify the indices of the parameters to be modeled with random effects in nlmeFit:

```
[phi,PSI,stats] = nlmeFit(time,concentration,subject, ...  
                          [],nlme_model,phi0, ...  
                          'REParamsSelect',[1 2 3])
```

```
phi =  
    2.8277  
    0.7728  
    0.4605  
   -1.3460
```

```
PSI =  
    0.3270         0         0  
         0    0.0250         0  
         0         0    0.0124
```

```
stats =  
    dfe: 58  
    logl: 54.5875  
    mse: 0.0066  
    rmse: 0.0780  
    errorparam: 0.0815  
    aic: -93.1750  
    bic: -94.8410  
    covb: [4x4 double]  
    sebeta: [0.2560 0.1066 0.1092 0.2244]  
    ires: [66x1 double]  
    pres: [66x1 double]  
    iwres: [66x1 double]  
    pwres: [66x1 double]  
    cwres: [66x1 double]
```


The log-likelihood `logl` is almost identical to what it was with random effects for all of the parameters, the Akaike information criterion `aic` is reduced from -91.1765 to -93.1750, and the Bayesian information criterion `bic` is reduced from -93.0506 to -94.8410. These measures support the decision to drop the fourth random effect.

Refitting the simplified model with a full covariance matrix allows for identification of correlations among the random effects. To do this, use the `CovPattern` parameter to specify the pattern of nonzero elements in the covariance matrix:

```
[phi,PSI,stats] = nlmeFit(time,concentration,subject, ...
                          [],nlme_model,phi0, ...
                          'REParamsSelect',[1 2 3], ...
                          'CovPattern',ones(3))
```

```
phi =
    2.8148
    0.8293
    0.5613
   -1.1407
```

```
PSI =
    0.4767    0.1152    0.0499
    0.1152    0.0321    0.0032
    0.0499    0.0032    0.0236
```

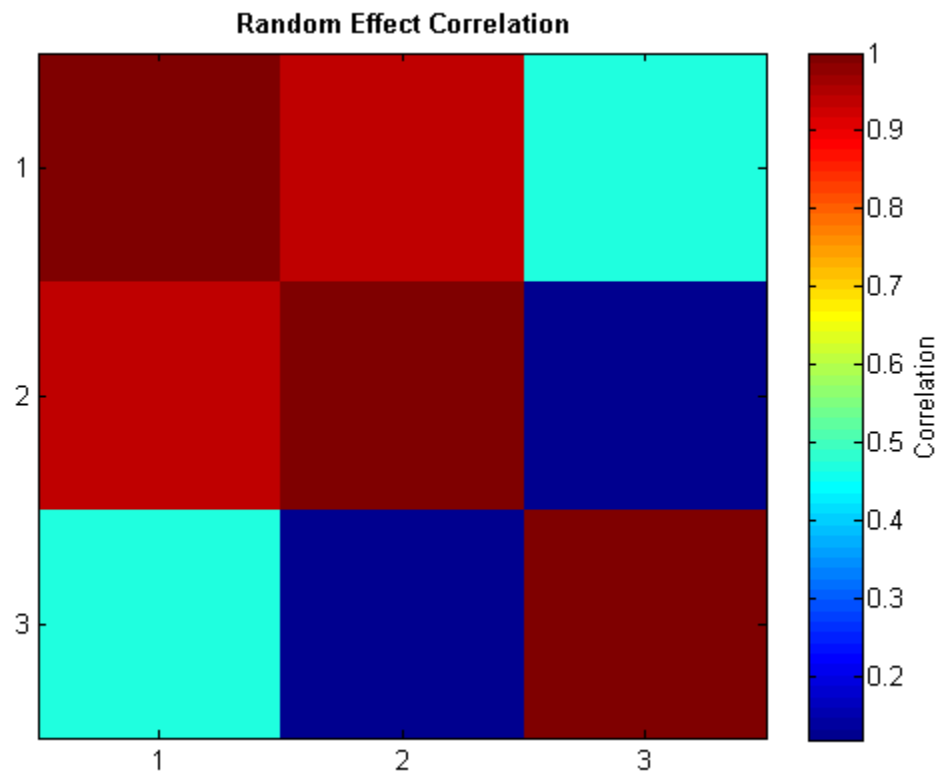
```
stats =
    dfe: 55
    logl: 58.4731
    mse: 0.0061
    rmse: 0.0782
    errorparam: 0.0781
    aic: -94.9462
    bic: -97.2369
    covb: [4x4 double]
    sebeta: [0.3028 0.1103 0.1179 0.1662]
    ires: [66x1 double]
    pres: [66x1 double]
    iwres: [66x1 double]
    pwres: [66x1 double]
```

```
    cwres: [66x1 double]
```

The estimated covariance matrix PSI shows that the random effects on the first two parameters have a relatively strong correlation, and both have a relatively weak correlation with the last random effect. This structure in the covariance matrix is more apparent if you convert PSI to a correlation matrix using `corrcoef`:

```
RHO = corrcoef(PSI)
RHO =
    1.0000    0.9316    0.4706
    0.9316    1.0000    0.1178
    0.4706    0.1178    1.0000

clf; imagesc(RHO)
set(gca,'XTick',[1 2 3],'YTick',[1 2 3])
title('\bf Random Effect Correlation')
h = colorbar;
set(get(h,'YLabel'),'String','Correlation');
```



Incorporate this structure into the model by changing the specification of the covariance pattern to block-diagonal:

```
P = [1 1 0;1 1 0;0 0 1] % Covariance pattern
P =
```

```
    1    1    0
    1    1    0
    0    0    1
```

```
[phi,PSI,stats,b] = nlmeFit(time,concentration,subject, ...
                             [],nlme_model,phi0, ...
                             'REParamsSelect',[1 2 3], ...
                             'CovPattern',P)
```

```
phi =
  2.7830
  0.8981
  0.6581
 -1.0000

PSI =
  0.5180    0.1069    0
  0.1069    0.0221    0
  0         0         0.0454

stats =
  dfe: 57
  logl: 58.0804
  mse: 0.0061
  rmse: 0.0768
  errorparam: 0.0782
  aic: -98.1608
  bic: -100.0350
  covb: [4x4 double]
  sebeta: [0.3171 0.1073 0.1384 0.1453]
  ires: [66x1 double]
  pres: [66x1 double]
  iwres: [66x1 double]
  pwres: [66x1 double]
  cwres: [66x1 double]

b =
 -0.8507  -0.1563   1.0427  -0.7559   0.5652   0.1550
 -0.1756  -0.0323   0.2152  -0.1560   0.1167   0.0320
 -0.2756   0.0519   0.2620   0.1064  -0.2835   0.1389
```

The block-diagonal covariance structure reduces `aic` from -94.9462 to -98.1608 and `bic` from -97.2368 to -100.0350 without significantly affecting the log-likelihood. These measures support the covariance structure used in the final model.

The output `b` gives predictions of the three random effects for each of the six subjects. These are combined with the estimates of the fixed effects in `phi` to produce the mixed-effects model.

Use the following commands to plot the mixed-effects model for each of the six subjects. For comparison, the model without random effects is also shown.

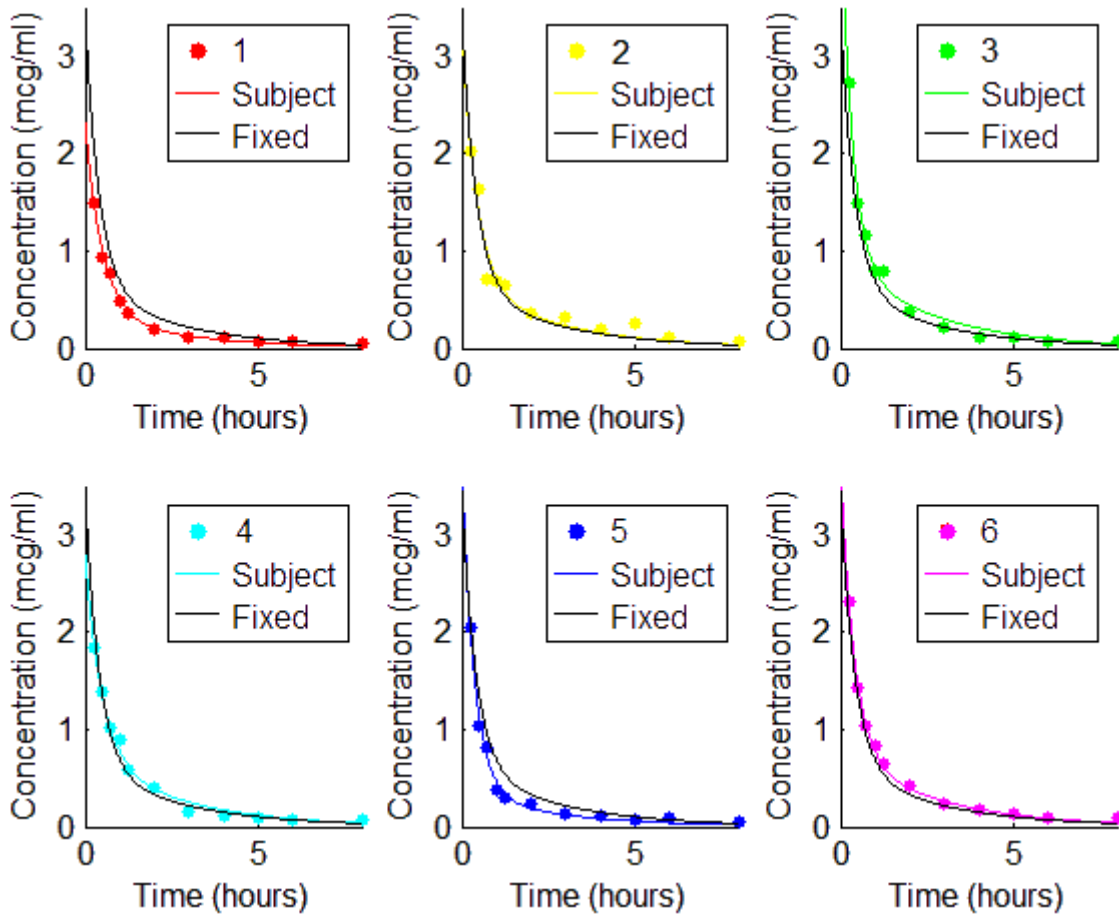
```

PHI = repmat(phi,1,6) + ...           % Fixed effects
      [b(1,:);b(2,:);b(3,:);zeros(1,6)]; % Random effects

RES = zeros(11,6); % Residuals
colors = 'rygcbm';
for I = 1:6
    fitted_model = @(t)(PHI(1,I)*exp(-exp(PHI(2,I))*t) + ...
                       PHI(3,I)*exp(-exp(PHI(4,I))*t));
    tI = time(subject == I);
    cI = concentration(subject == I);
    RES(:,I) = cI - fitted_model(tI);

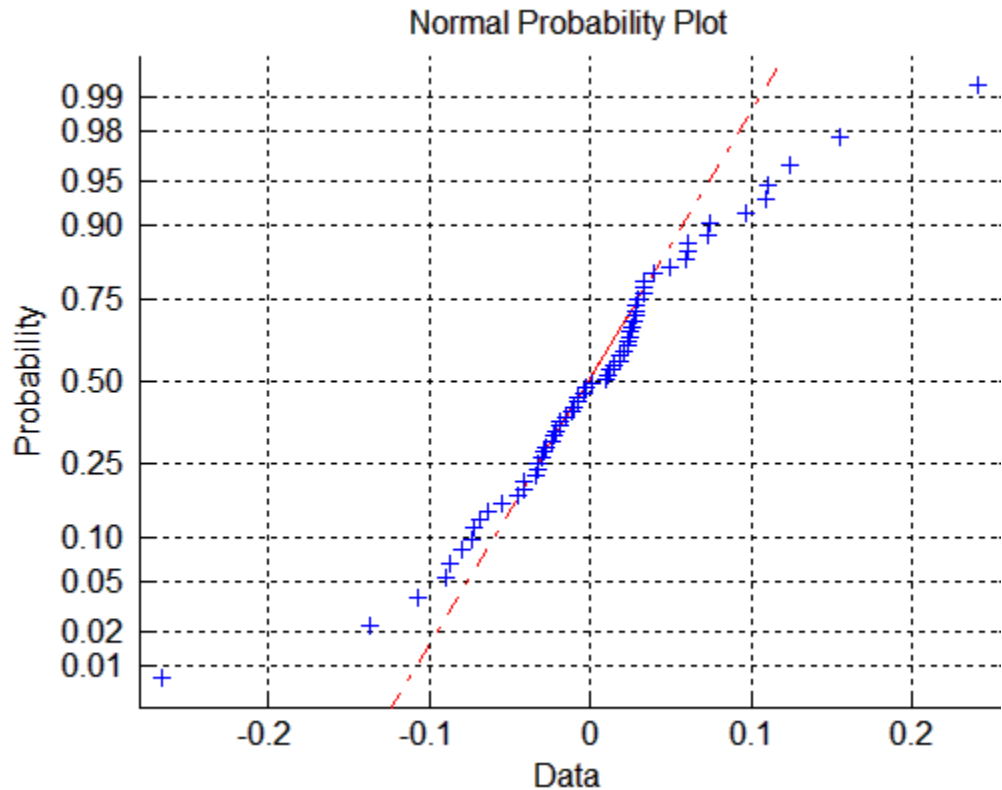
    subplot(2,3,I)
    scatter(tI,cI,20,colors(I),'filled')
    hold on
    plot(tplot,fitted_model(tplot),'Color',colors(I))
    plot(tplot,model(phi,tplot),'k')
    axis([0 8 0 3.5])
    xlabel('Time (hours)')
    ylabel('Concentration (mcg/ml)')
    legend(num2str(I),'Subject','Fixed')
end

```



If obvious outliers in the data (visible in previous box plots) are ignored, a normal probability plot of the residuals shows reasonable agreement with model assumptions on the errors:

```
clf; normplot(RES(:))
```



Examining Residuals for Model Verification

You can examine the `stats` structure, which is returned by both `nlmefit` and `nlmefitsa`, to determine the quality of your model. The `stats` structure contains fields with conditional weighted residuals (`cwres` field) and individual weighted residuals (`iwres` field). Since the model assumes that residuals are normally distributed, you can examine the residuals to see how well this assumption holds.

This example generates synthetic data using normal distributions. It shows how the fit statistics look:

- Good when testing against the same type of model as generates the data
- Poor when tested against incorrect data models

- 1 Initialize a 2-D model with 100 individuals:

```
nGroups = 100; % 100 Individuals
nlmefun = @(PHI,t)(PHI(:,1)*5 + PHI(:,2)^2.*t); % Regression fcn
REParamSelect = [1 2]; % Both Parameters have random effect
errorParam = .03;
beta0 = [ 1.5 5]; % Parameter means
psi = [ 0.35 0; ... % Covariance Matrix
       0 0.51 ];
time =[0.25;0.5;0.75;1;1.25;2;3;4;5;6];
nParameters = 2;
rng(0,'twister') % for reproducibility
```

- 2 Generate the data for fitting with a proportional error model:

```
b_i = mvnrnd(zeros(1, numel(REParamSelect)), psi, nGroups);
individualParameters = zeros(nGroups,nParameters);
individualParameters(:, REParamSelect) = ...
    bsxfun(@plus,beta0(REParamSelect), b_i);

groups = repmat(1:nGroups,numel(time),1);
groups = vertcat(groups(:));

y = zeros(numel(time)*nGroups,1);
x = zeros(numel(time)*nGroups,1);
for i = 1:nGroups
    idx = groups == i;
    f = nlmefun(individualParameters(i,:), time);
    % Make a proportional error model for y:
    y(idx) = f + errorParam*f.*randn(numel(f),1);
    x(idx) = time;
end

P = [ 1 0 ; 0 1 ];
```

- 3 Fit the data using the same regression function and error model as the model generator:

```
[~,~,stats] = nlmefit(x,y,groups, ...
    [],nlmefun,[1 1], 'REParamsSelect', REParamSelect, ...
    'ErrorModel', 'Proportional', 'CovPattern', P);
```


- 4** Create a plotting routine by copying the following function definition, and creating a file `plotResiduals.m` on your MATLAB path:

```
function plotResiduals(stats)
pwres = stats.pwres;
iwres = stats.iwres;
cwres = stats.cwres;
figure
subplot(2,3,1);
normplot(pwres); title('PWRES')
subplot(2,3,4);
createhistplot(pwres);

subplot(2,3,2);
normplot(cwres); title('CWRES')
subplot(2,3,5);
createhistplot(cwres);

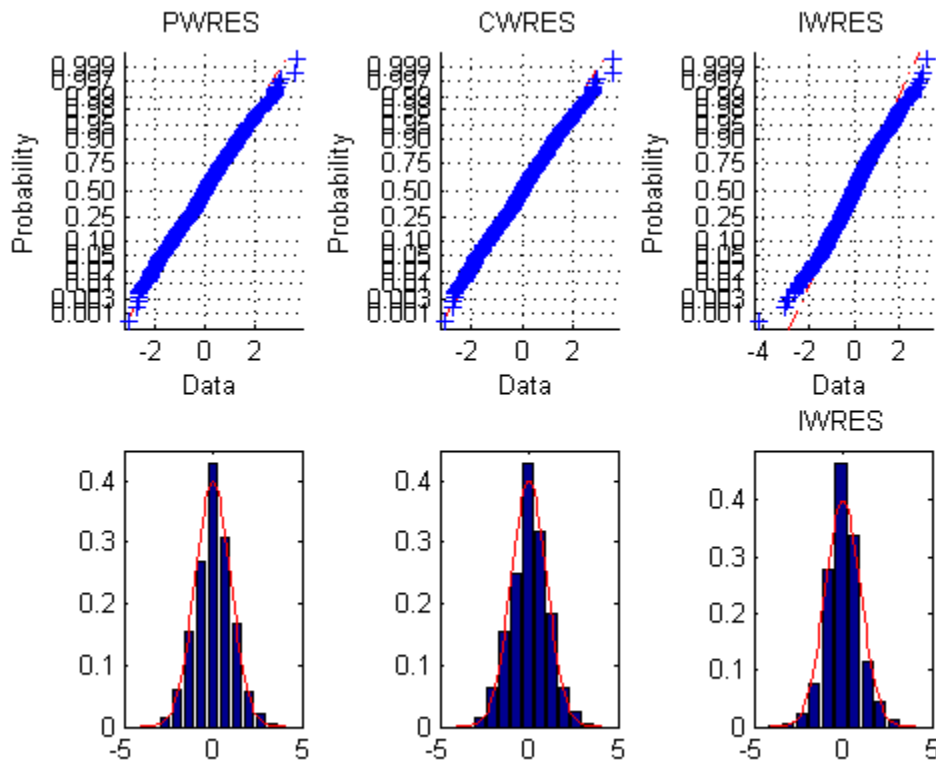
subplot(2,3,3);
normplot(iwres); title('IWRES')
subplot(2,3,6);
createhistplot(iwres); title('IWRES')

function createhistplot(pwres)
[x, n] = hist(pwres);
d = n(2)- n(1);
x = x/sum(x*d);
bar(n,x);
ylim([0 max(x)*1.05]);
hold on;
x2 = -4:0.1:4;
f2 = normpdf(x2,0,1);
plot(x2,f2,'r');
end

end
```

- 5** Plot the residuals using the `plotResiduals` function:

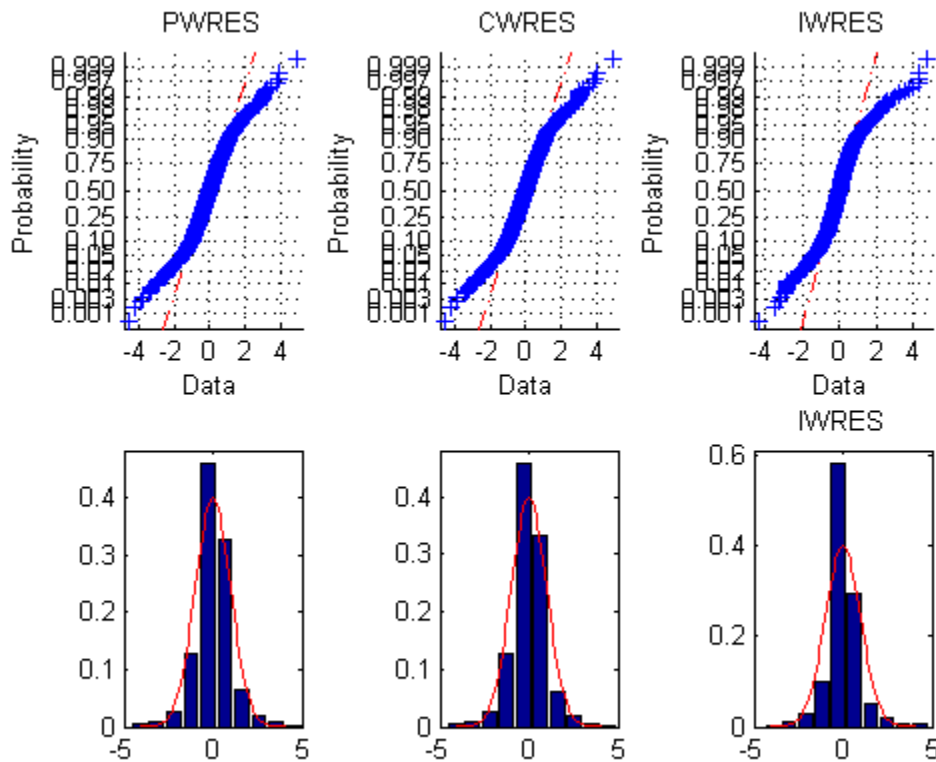
```
plotResiduals(stats);
```



The upper probability plots look straight, meaning the residuals are normally distributed. The bottom histogram plots match the superimposed normal density plot. So you can conclude that the error model matches the data.

- For comparison, fit the data using a constant error model, instead of the proportional model that created the data:

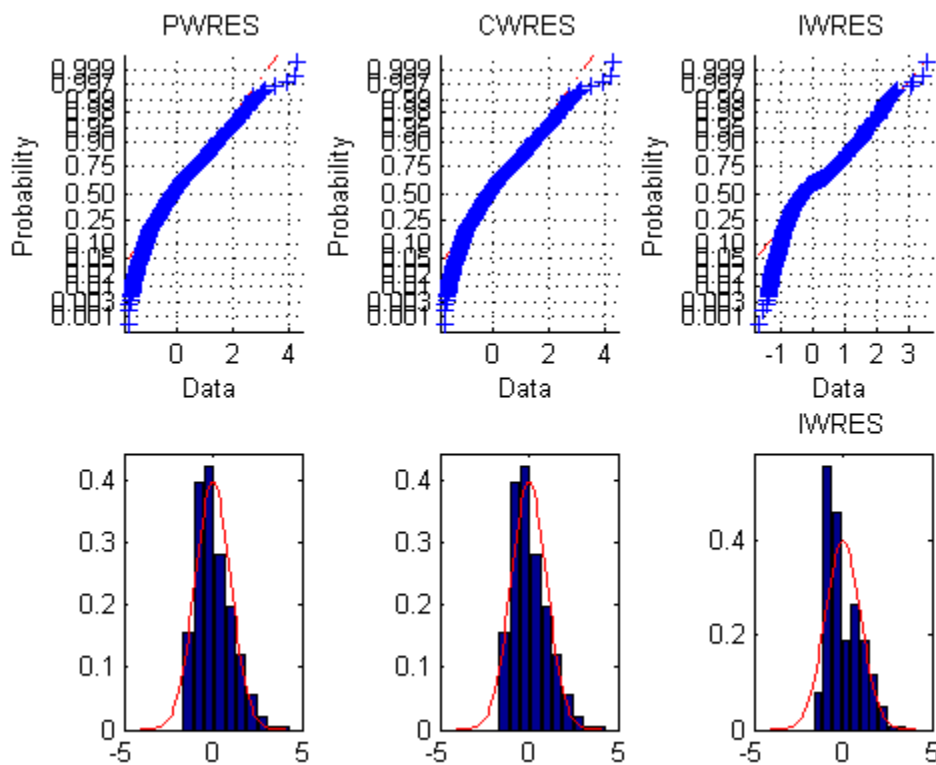
```
[~,~,stats] = nlmefit(x,y,groups, ...
    [],nlmefun,[0 0], 'REParamsSelect',REParamSelect,...
    'ErrorModel','Constant','CovPattern',P);
plotResiduals(stats);
```



The upper probability plots are not straight, indicating the residuals are not normally distributed. The bottom histogram plots are fairly close to the superimposed normal density plots.

- 7 For another comparison, fit the data to a different structural model than created the data:

```
nlmefun2 = @(PHI,t)(PHI(:,1)*5 + PHI(:,2).*t.^4);
[~,~,stats] = nlmefit(x,y,groups, ...
    [],nlmefun2,[0 0], 'REParamsSelect',REParamSelect,...
    'ErrorModel','constant', 'CovPattern',P);
plotResiduals(stats);
```



Not only are the upper probability plots not straight, but the histogram plot is quite skewed compared to the superimposed normal density. These residuals are not normally distributed, and do not match the model.

Pitfalls in Fitting Nonlinear Models by Transforming to Linearity

This example shows pitfalls that can occur when fitting a nonlinear model by transforming to linearity. Imagine that we have collected measurements on two variables, x and y , and we want to model y as a function of x . Assume that x is measured exactly, while measurements of y are affected by additive, symmetric, zero-mean errors.

```
x = [5.72 4.22 5.72 3.59 5.04 2.66 5.02 3.11 0.13 2.26 ...
      5.39 2.57 1.20 1.82 3.23 5.46 3.15 1.84 0.21 4.29 ...
      4.61 0.36 3.76 1.59 1.87 3.14 2.45 5.36 3.44 3.41]';
y = [2.66 2.91 0.94 4.28 1.76 4.08 1.11 4.33 8.94 5.25 ...
      0.02 3.88 6.43 4.08 4.90 1.33 3.63 5.49 7.23 0.88 ...
      3.08 8.12 1.22 4.24 6.21 5.48 4.89 2.30 4.13 2.17]';
```

Let's also assume that theory tells us that these data should follow a model of exponential decay, $y = p_1 \exp(p_2 x)$, where p_1 is positive and p_2 is negative. To fit this model, we could use nonlinear least squares.

```
modelFun = @(p,x) p(1)*exp(p(2)*x);
```

But the nonlinear model can also be transformed to a linear one by taking the log on both sides, to get $\log(y) = \log(p_1) + p_2 x$. That's tempting, because we can fit that linear model by ordinary linear least squares. The coefficients we'd get from a linear least squares would be $\log(p_1)$ and p_2 .

```
paramEstsLin = [ones(size(x)), x] \ log(y);
paramEstsLin(1) = exp(paramEstsLin(1))
```

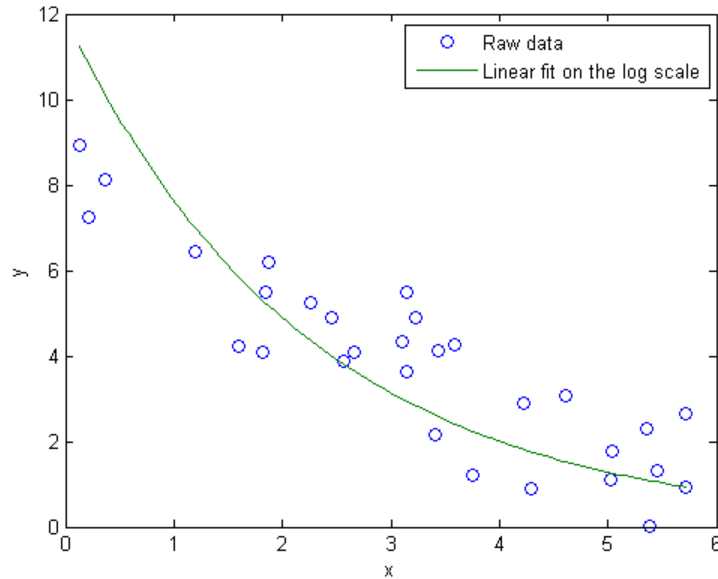
```
paramEstsLin =
```

```
11.9312
-0.4462
```

How did we do? We can superimpose the fit on the data to find out.

```
xx = linspace(min(x), max(x));
```

```
yyLin = modelFun(paramEstsLin, xx);  
plot(x,y,'o', xx,yyLin,'-');  
xlabel('x'); ylabel('y');  
legend({'Raw data','Linear fit on the log scale'},'location','NE');
```



Something seems to have gone wrong, because the fit doesn't really follow the trend that we can see in the raw data. What kind of fit would we get if we used `nlinfit` to do nonlinear least squares instead? We'll use the previous fit as a rough starting point, even though it's not a great fit.

```
paramEsts = nlinfit(x, y, modelFun, paramEstsLin)
```

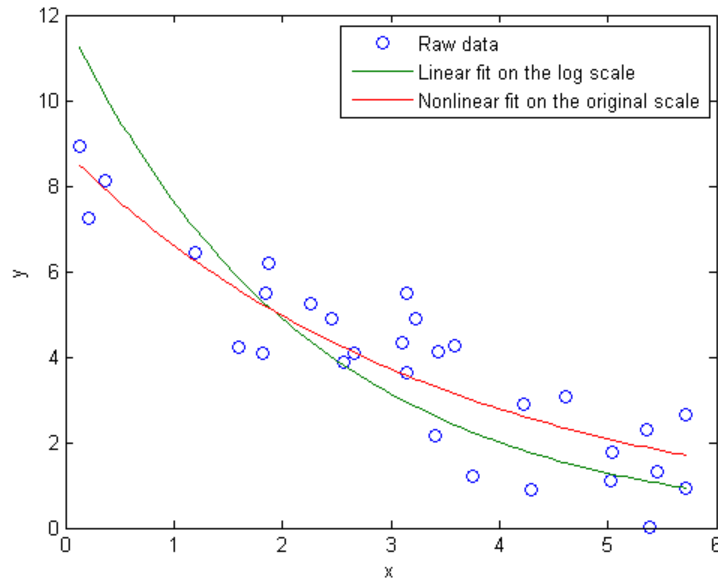
```
paramEsts =
```

```
8.8145  
-0.2885
```

```

yy = modelFun(paramEsts,xx);
plot(x,y,'o', xx,yyLin,'- ', xx,yy,'- ');
xlabel('x'); ylabel('y');
legend({'Raw data','Linear fit on the log scale', ...
'Nonlinear fit on the original scale'],'location','NE');

```

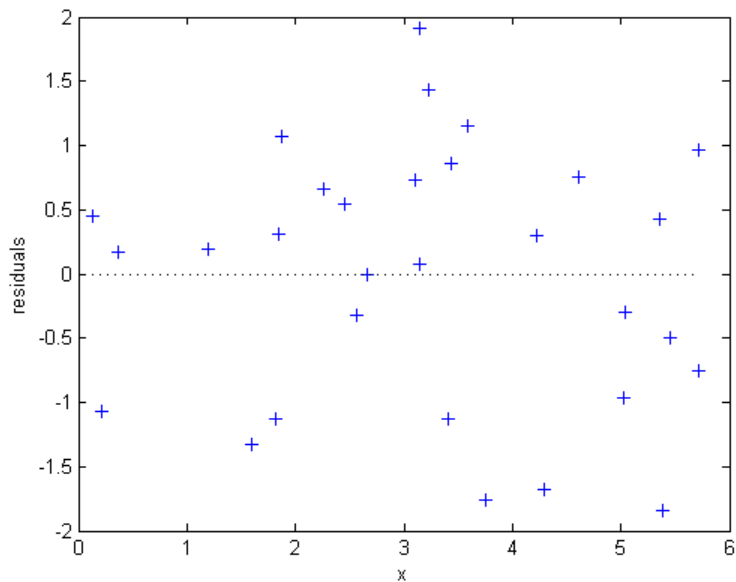


The fit using `nlinfit` more or less passes through the center of the data point scatter. A residual plot shows something approximately like an even scatter about zero.

```

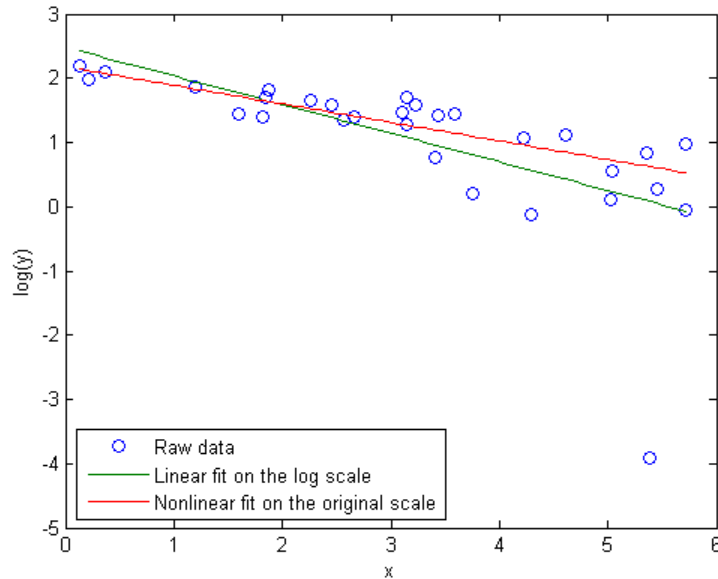
r = y-modelFun(paramEsts,x);
plot(x,r,'+', [min(x) max(x)], [0 0], 'k:');
xlabel('x'); ylabel('residuals');

```



So what went wrong with the linear fit? The problem is in log transform. If we plot the data and the two fits on the log scale, we can see that there's an extreme outlier.

```
plot(x,log(y),'o', xx,log(yyLin),'- ', xx,log(yy),'- ');
xlabel('x'); ylabel('log(y)');
ylim([-5,3]);
legend({'Raw data', 'Linear fit on the log scale', ...
       'Nonlinear fit on the original scale'},'location','SW');
```

That observation is not an outlier in the original data, so what happened to make it one on the log scale? The log transform is exactly the right thing to straighten out the trend line. But the log is a very nonlinear transform, and so symmetric measurement errors on the original scale have become asymmetric on the log scale. Notice that the outlier had the smallest y value on the original scale -- close to zero. The log transform has "stretched out" that smallest y value more than its neighbors. We made the linear fit on the log scale, and so it is very much affected by that outlier.

Had the measurement at that one point been slightly different, the two fits might have been much more similar. For example,

```
y(11) = 1;
paramEsts = nlinfit(x, y, modelFun, [10;-.3])
```

```
paramEsts =
```

```
8.7618
```

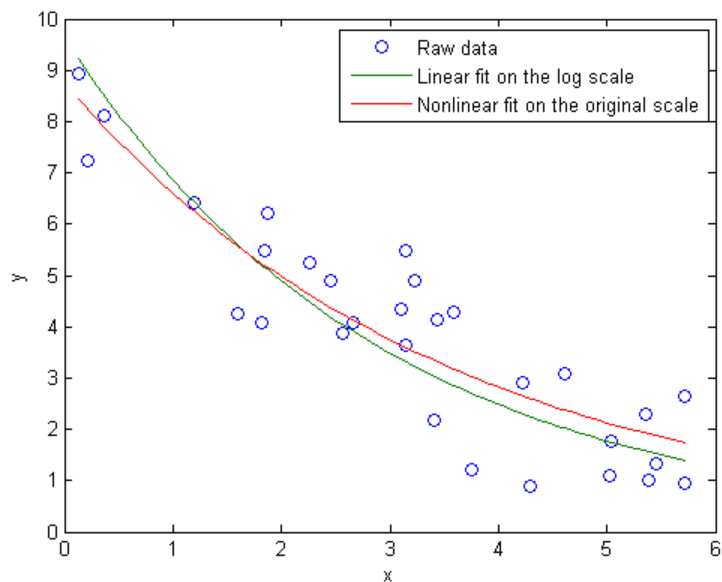
```
-0.2833
```

```
paramEstsLin = [ones(size(x)), x] \ log(y);  
paramEstsLin(1) = exp(paramEstsLin(1))
```

```
paramEstsLin =
```

```
9.6357  
-0.3394
```

```
yy = modelFun(paramEsts,xx);  
yyLin = modelFun(paramEstsLin, xx);  
plot(x,y,'o', xx,yyLin,'-', xx,yy,'-');  
xlabel('x'); ylabel('y');  
legend({'Raw data', 'Linear fit on the log scale', ...  
       'Nonlinear fit on the original scale'},'location','NE');
```



Still, the two fits are different. Which one is "right"? To answer that, suppose that instead of additive measurement errors, measurements of y were affected by multiplicative errors. These errors would not be symmetric, and least squares on the original scale would not be appropriate. On the other hand, the log transform would make the errors symmetric on the log scale, and the linear least squares fit on that scale is appropriate.

So, which method is "right" depends on what assumptions you are willing to make about your data. In practice, when the noise term is small relative to the trend, the log transform is "locally linear" in the sense that y values near the same x value will not be stretched out too asymmetrically. In that case, the two methods lead to essentially the same fit. But when the noise term is not small, you should consider what assumptions are realistic, and choose an appropriate fitting method.

Multivariate Methods

- “Introduction to Multivariate Methods” on page 10-2
- “Multidimensional Scaling” on page 10-3
- “Procrustes Analysis” on page 10-14
- “Feature Selection” on page 10-23
- “Feature Transformation” on page 10-28
- “Partial Least Squares Regression and Principal Components Regression” on page 10-55

Introduction to Multivariate Methods

Large, high-dimensional data sets are common in the modern era of computer-based instrumentation and electronic data storage. High-dimensional data present many challenges for statistical visualization, analysis, and modeling.

Data visualization, of course, is impossible beyond a few dimensions. As a result, pattern recognition, data preprocessing, and model selection must rely heavily on numerical methods.

A fundamental challenge in high-dimensional data analysis is the so-called *curse of dimensionality*. Observations in a high-dimensional space are necessarily sparser and less representative than those in a low-dimensional space. In higher dimensions, data over-represent the edges of a sampling distribution, because regions of higher-dimensional space contain the majority of their volume near the surface. (A d -dimensional spherical shell has a volume, relative to the total volume of the sphere, that approaches 1 as d approaches infinity.) In high dimensions, typical data points at the interior of a distribution are sampled less frequently.

Often, many of the dimensions in a data set—the measured features—are not useful in producing a model. Features may be irrelevant or redundant. Regression and classification algorithms may require large amounts of storage and computation time to process raw data, and even if the algorithms are successful the resulting models may contain an incomprehensible number of terms.

Because of these challenges, multivariate statistical methods often begin with some type of *dimension reduction*, in which data are approximated by points in a lower-dimensional space. Dimension reduction is the goal of the methods presented in this chapter. Dimension reduction often leads to simpler models and fewer measured variables, with consequent benefits when measurements are expensive and visualization is important.

Multidimensional Scaling

In this section...

“Introduction to Multidimensional Scaling” on page 10-3

“Classical Multidimensional Scaling” on page 10-3

“Nonclassical Multidimensional Scaling” on page 10-8

“Nonmetric Multidimensional Scaling” on page 10-10

Introduction to Multidimensional Scaling

One of the most important goals in visualizing data is to get a sense of how near or far points are from each other. Often, you can do this with a scatter plot. However, for some analyses, the data that you have might not be in the form of points at all, but rather in the form of pairwise similarities or dissimilarities between cases, observations, or subjects. There are no points to plot.

Even if your data are in the form of points rather than pairwise distances, a scatter plot of those data might not be useful. For some kinds of data, the relevant way to measure how near two points are might not be their Euclidean distance. While scatter plots of the raw data make it easy to compare Euclidean distances, they are not always useful when comparing other kinds of inter-point distances, city block distance for example, or even more general dissimilarities. Also, with a large number of variables, it is very difficult to visualize distances unless the data can be represented in a small number of dimensions. Some sort of dimension reduction is usually necessary.

Multidimensional scaling (MDS) is a set of methods that address all these problems. MDS allows you to visualize how near points are to each other for many kinds of distance or dissimilarity metrics and can produce a representation of your data in a small number of dimensions. MDS does not require raw data, but only a matrix of pairwise distances or dissimilarities.

Classical Multidimensional Scaling

- “Introduction to Classical Multidimensional Scaling” on page 10-4

- “Example: Multidimensional Scaling” on page 10-6

Introduction to Classical Multidimensional Scaling

The function `cmdscale` performs classical (metric) multidimensional scaling, also known as *principal coordinates analysis*. `cmdscale` takes as an input a matrix of inter-point distances and creates a configuration of points. Ideally, those points are in two or three dimensions, and the Euclidean distances between them reproduce the original distance matrix. Thus, a scatter plot of the points created by `cmdscale` provides a visual representation of the original distances.

As a very simple example, you can reconstruct a set of points from only their inter-point distances. First, create some four dimensional points with a small component in their fourth coordinate, and reduce them to distances.

```
X = [ normrnd(0,1,10,3), normrnd(0,.1,10,1) ];  
D = pdist(X,'euclidean');
```

Next, use `cmdscale` to find a configuration with those inter-point distances. `cmdscale` accepts distances as either a square matrix, or, as in this example, in the vector upper-triangular form produced by `pdist`.

```
[Y,eigvals] = cmdscale(D);
```

`cmdscale` produces two outputs. The first output, `Y`, is a matrix containing the reconstructed points. The second output, `eigvals`, is a vector containing the sorted eigenvalues of what is often referred to as the “scalar product matrix,” which, in the simplest case, is equal to $Y*Y'$. The relative magnitudes of those eigenvalues indicate the relative contribution of the corresponding columns of `Y` in reproducing the original distance matrix `D` with the reconstructed points.

```
format short g  
[eigvals eigvals/max(abs(eigvals))]  
ans =  
    12.623         1  
    4.3699        0.34618  
    1.9307        0.15295  
    0.025884     0.0020505  
    1.7192e-015  1.3619e-016  
    6.8727e-016  5.4445e-017
```



```

4.4367e-017  3.5147e-018
-9.2731e-016 -7.3461e-017
-1.327e-015  -1.0513e-016
-1.9232e-015 -1.5236e-016

```

If `eigvals` contains only positive and zero (within round-off error) eigenvalues, the columns of `Y` corresponding to the positive eigenvalues provide an exact reconstruction of `D`, in the sense that their inter-point Euclidean distances, computed using `pdist`, for example, are identical (within round-off) to the values in `D`.

```

maxerr4 = max(abs(D - pdist(Y))) % exact reconstruction
maxerr4 =
    2.6645e-015

```

If two or three of the eigenvalues in `eigvals` are much larger than the rest, then the distance matrix based on the corresponding columns of `Y` nearly reproduces the original distance matrix `D`. In this sense, those columns form a lower-dimensional representation that adequately describes the data. However it is not always possible to find a good low-dimensional reconstruction.

```

% good reconstruction in 3D
maxerr3 = max(abs(D - pdist(Y(:,1:3))))
maxerr3 =
    0.029728

```

```

% poor reconstruction in 2D
maxerr2 = max(abs(D - pdist(Y(:,1:2))))
maxerr2 =
    0.91641

```

The reconstruction in three dimensions reproduces `D` very well, but the reconstruction in two dimensions has errors that are of the same order of magnitude as the largest values in `D`.

```

max(max(D))
ans =
    3.4686

```

Often, `eigvals` contains some negative eigenvalues, indicating that the distances in `D` cannot be reproduced exactly. That is, there might not be any configuration of points whose inter-point Euclidean distances are given by `D`. If the largest negative eigenvalue is small in magnitude relative to the largest positive eigenvalues, then the configuration returned by `cmdscale` might still reproduce `D` well.

Example: Multidimensional Scaling

Given only the distances between 10 US cities, `cmdscale` can construct a map of those cities. First, create the distance matrix and pass it to `cmdscale`. In this example, `D` is a full distance matrix: it is square and symmetric, has positive entries off the diagonal, and has zeros on the diagonal.

```
cities = ...
{'Atl', 'Chi', 'Den', 'Hou', 'LA', 'Mia', 'NYC', 'SF', 'Sea', 'WDC'};
D = [
    0 587 1212 701 1936 604 748 2139 2182 543;
    587 0 920 940 1745 1188 713 1858 1737 597;
    1212 920 0 879 831 1726 1631 949 1021 1494;
    701 940 879 0 1374 968 1420 1645 1891 1220;
    1936 1745 831 1374 0 2339 2451 347 959 2300;
    604 1188 1726 968 2339 0 1092 2594 2734 923;
    748 713 1631 1420 2451 1092 0 2571 2408 205;
    2139 1858 949 1645 347 2594 2571 0 678 2442;
    2182 1737 1021 1891 959 2734 2408 678 0 2329;
    543 597 1494 1220 2300 923 205 2442 2329 0];
[Y,eigvals] = cmdscale(D);
```

Next, look at the eigenvalues returned by `cmdscale`. Some of these are negative, indicating that the original distances are not Euclidean. This is because of the curvature of the earth.

```
format short g
[eigvals eigvals/max(abs(eigvals))]
ans =
    9.5821e+006         1
    1.6868e+006     0.17604
    8157.3     0.0008513
    1432.9     0.00014954
    508.67    5.3085e-005
    25.143    2.624e-006
```

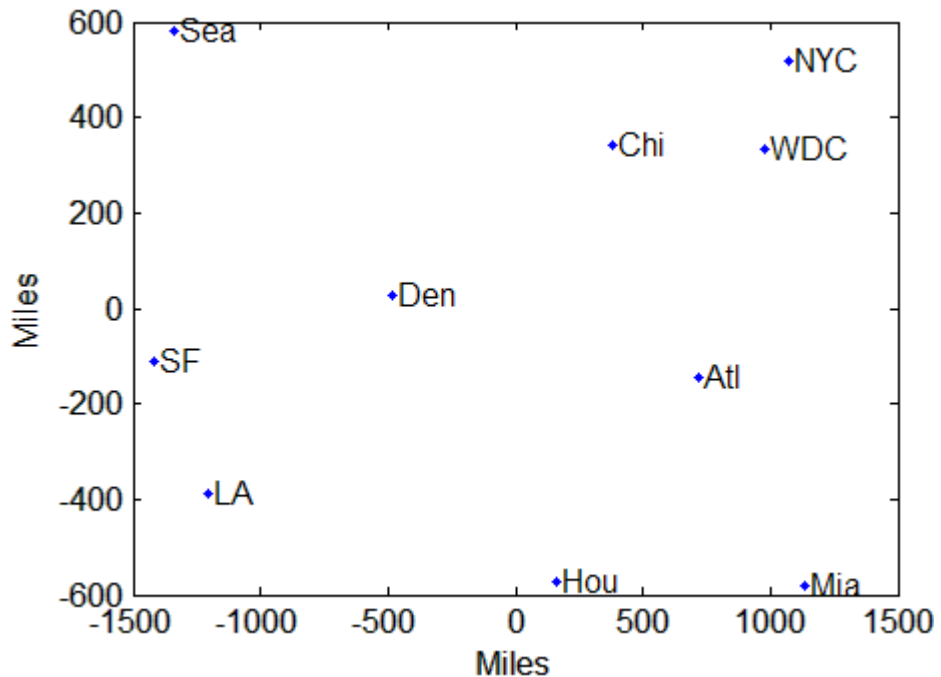
```
5.3394e-010  5.5722e-017
-897.7 -9.3685e-005
-5467.6 -0.0005706
-35479 -0.0037026
```

However, in this case, the two largest positive eigenvalues are much larger in magnitude than the remaining eigenvalues. So, despite the negative eigenvalues, the first two coordinates of Y are sufficient for a reasonable reproduction of D .

```
Dtriu = D(find(tril(ones(10),-1)))';
maxrelerr = max(abs(Dtriu-pdist(Y(:,1:2))))./max(Dtriu)
maxrelerr =
    0.0075371
```

Here is a plot of the reconstructed city locations as a map. The orientation of the reconstruction is arbitrary. In this case, it happens to be close to, although not exactly, the correct orientation.

```
plot(Y(:,1),Y(:,2),'.')
text(Y(:,1)+25,Y(:,2),cities)
xlabel('Miles')
ylabel('Miles')
```



Nonclassical Multidimensional Scaling

The function `mdscale` performs nonclassical multidimensional scaling. As with `cmdscale`, you use `mdscale` either to visualize dissimilarity data for which no “locations” exist, or to visualize high-dimensional data by reducing its dimensionality. Both functions take a matrix of dissimilarities as an input and produce a configuration of points. However, `mdscale` offers a choice of different criteria to construct the configuration, and allows missing data and weights.

For example, the cereal data include measurements on 10 variables describing breakfast cereals. You can use `mdscale` to visualize these data in two dimensions. First, load the data. For clarity, this example code selects a subset of 22 of the observations.

```
load cereal.mat
X = [Calories Protein Fat Sodium Fiber ...
     Carbo Sugars Shelf Potass Vitamins];
```

```
% Take a subset from a single manufacturer
mfg1 = strcmp('G',cellstr(Mfg));
X = X(mfg1,:);
size(X)
ans =
    22 10
```

Then use `pdist` to transform the 10-dimensional data into dissimilarities. The output from `pdist` is a symmetric dissimilarity matrix, stored as a vector containing only the $(23*22/2)$ elements in its upper triangle.

```
dissimilarities = pdist(zscore(X),'cityblock');
size(dissimilarities)
ans =
    1    231
```

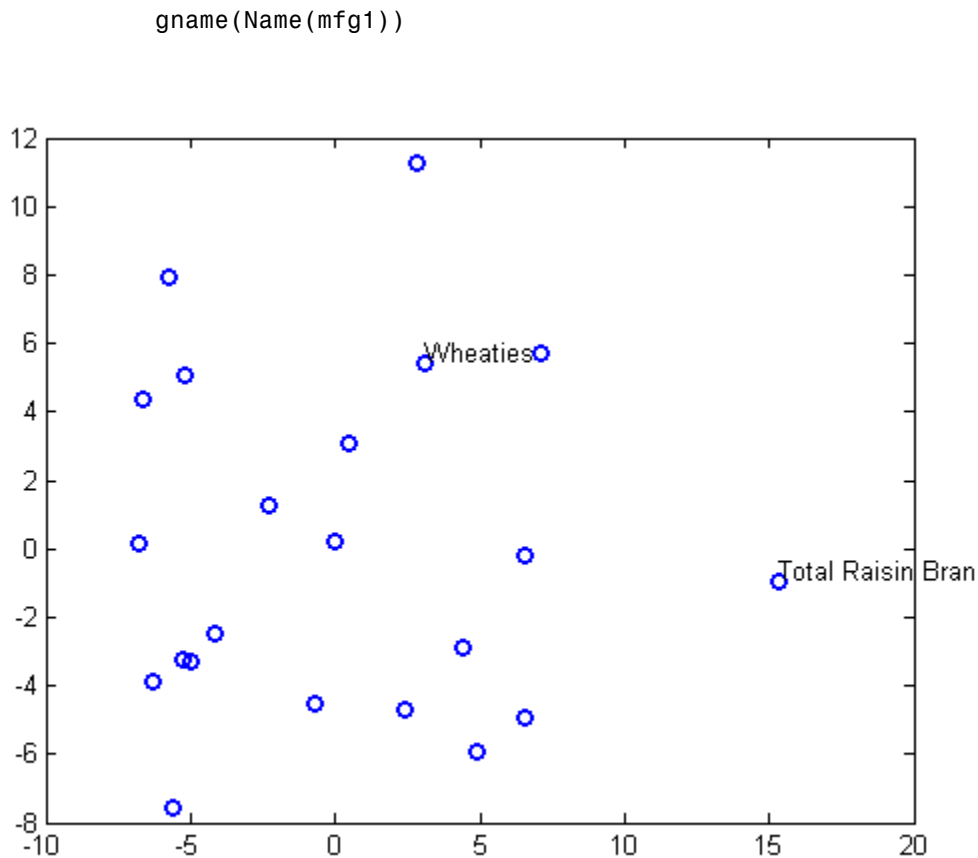
This example code first standardizes the cereal data, and then uses city block distance as a dissimilarity. The choice of transformation to dissimilarities is application-dependent, and the choice here is only for simplicity. In some applications, the original data are already in the form of dissimilarities.

Next, use `mdscale` to perform metric MDS. Unlike `cmdscale`, you must specify the desired number of dimensions, and the method to use to construct the output configuration. For this example, use two dimensions. The metric STRESS criterion is a common method for computing the output; for other choices, see the `mdscale` reference page in the online documentation. The second output from `mdscale` is the value of that criterion evaluated for the output configuration. It measures the how well the inter-point distances of the output configuration approximate the original input dissimilarities:

```
[Y, stress] = ...
mdscale(dissimilarities,2,'criterion','metricstress');
stress
stress =
    0.1856
```

A scatterplot of the output from `mdscale` represents the original 10-dimensional data in two dimensions, and you can use the `gname` function to label selected points:

```
plot(Y(:,1),Y(:,2),'o','LineWidth',2);
```



Nonmetric Multidimensional Scaling

Metric multidimensional scaling creates a configuration of points whose inter-point distances approximate the given dissimilarities. This is sometimes too strict a requirement, and non-metric scaling is designed to relax it a bit. Instead of trying to approximate the dissimilarities themselves, non-metric scaling approximates a nonlinear, but monotonic, transformation of them. Because of the monotonicity, larger or smaller distances on a plot of the output will correspond to larger or smaller dissimilarities, respectively. However, the nonlinearity implies that `mdscale` only attempts to preserve the

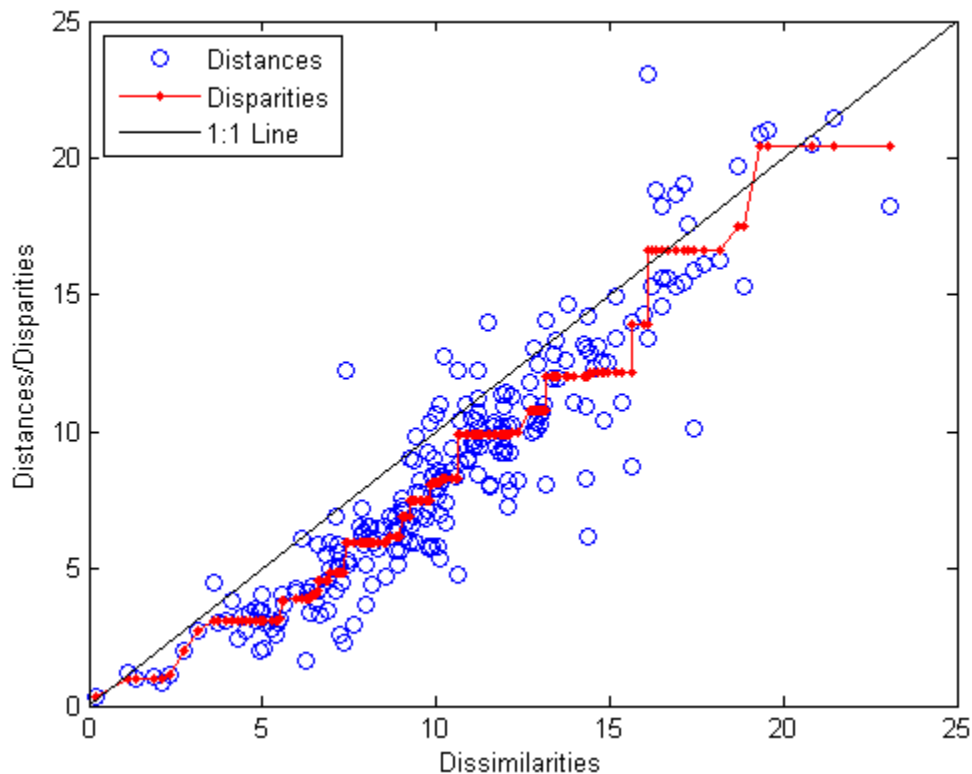
ordering of dissimilarities. Thus, there may be contractions or expansions of distances at different scales.

You use `mdscale` to perform nonmetric MDS in much the same way as for metric scaling. The nonmetric STRESS criterion is a common method for computing the output; for more choices, see the `mdscale` reference page in the online documentation. As with metric scaling, the second output from `mdscale` is the value of that criterion evaluated for the output configuration. For nonmetric scaling, however, it measures the how well the inter-point distances of the output configuration approximate the disparities. The disparities are returned in the third output. They are the transformed values of the original dissimilarities:

```
[Y, stress, disparities] = ...
mdscale(dissimilarities, 2, 'criterion', 'stress');
stress
stress =
    0.1562
```

To check the fit of the output configuration to the dissimilarities, and to understand the disparities, it helps to make a Shepard plot:

```
distances = pdist(Y);
[dum, ord] = sortrows([disparities(:) dissimilarities(:)]);
plot(dissimilarities, distances, 'bo', ...
     dissimilarities(ord), disparities(ord), 'r.-', ...
     [0 25], [0 25], 'k-')
xlabel('Dissimilarities')
ylabel('Distances/Disparities')
legend({'Distances' 'Disparities' '1:1 Line'}, ...
     'Location', 'NorthWest');
```



This plot shows that `mdscale` has found a configuration of points in two dimensions whose inter-point distances approximates the disparities, which in turn are a nonlinear transformation of the original dissimilarities. The concave shape of the disparities as a function of the dissimilarities indicates that fit tends to contract small distances relative to the corresponding dissimilarities. This may be perfectly acceptable in practice.

`mdscale` uses an iterative algorithm to find the output configuration, and the results can often depend on the starting point. By default, `mdscale` uses `cmdscale` to construct an initial configuration, and this choice often leads to a globally best solution. However, it is possible for `mdscale` to stop at a configuration that is a local minimum of the criterion. Such

cases can be diagnosed and often overcome by running `mdscale` multiple times with different starting points. You can do this using the `'start'` and `'replicates'` parameters. The following code runs five replicates of MDS, each starting at a different randomly-chosen initial configuration. The criterion value is printed out for each replication; `mdscale` returns the configuration with the best fit.

```
opts = statset('Display','final');  
[Y, stress] = ...  
mdscale(dissimilarities,2,'criterion','stress',...  
'start','random','replicates',5,'Options',opts);
```

```
35 iterations, Final stress criterion = 0.156209  
31 iterations, Final stress criterion = 0.156209  
48 iterations, Final stress criterion = 0.171209  
33 iterations, Final stress criterion = 0.175341  
32 iterations, Final stress criterion = 0.185881
```

Notice that `mdscale` finds several different local solutions, some of which do not have as low a stress value as the solution found with the `cmdscale` starting point.

Procrustes Analysis

In this section...

“Compare Landmark Data” on page 10-14

“Data Input” on page 10-14

“Preprocess Data for Accurate Results” on page 10-15

“Compare Handwritten Shapes” on page 10-16

Compare Landmark Data

The `procrustes` function analyzes the distribution of a set of shapes using Procrustes analysis. This analysis method matches landmark data (geometric locations representing significant features in a given shape) to calculate the best shape-preserving Euclidian transformations. These transformations minimize the differences in location between compared landmark data.

Procrustes analysis is also useful in conjunction with multidimensional scaling. In “Example: Multidimensional Scaling” on page 10-6 there is an observation that the orientation of the reconstructed points is arbitrary. Two different applications of multidimensional scaling could produce reconstructed points that are very similar in principle, but that look different because they have different orientations. The `procrustes` function transforms one set of points to make them more comparable to the other.

Data Input

The `procrustes` function takes two matrices as input:

- The target shape matrix X has dimension $n \times p$, where n is the number of landmarks in the shape and p is the number of measurements per landmark.
- The comparison shape matrix Y has dimension $n \times q$ with $q \leq p$. If there are fewer measurements per landmark for the comparison shape than the target shape ($q < p$), the function adds columns of zeros to Y , yielding an $n \times p$ matrix.

The equation to obtain the transformed shape, Z , is

$$Z = bYT + c \quad (10-1)$$

where:

- b is a scaling factor that stretches ($b > 1$) or shrinks ($b < 1$) the points.
- T is the orthogonal rotation and reflection matrix.
- c is a matrix with constant values in each column, used to shift the points.

The `procrustes` function chooses b , T , and c to minimize the distance between the target shape X and the transformed shape Z as measured by the least squares criterion:

$$\sum_{i=1}^n \sum_{j=1}^p (X_{ij} - Z_{ij})^2$$

Preprocess Data for Accurate Results

Procrustes analysis is appropriate when all p measurement dimensions have similar scales. The analysis would be inaccurate, for example, if the columns of Z had different scales:

- The first column is measured in milliliters ranging from 2,000 to 6,000.
- The second column is measured in degrees Celsius ranging from 10 to 25.
- The third column is measured in kilograms ranging from 50 to 230.

In such cases, standardize your variables by:

- 1 Subtracting the sample mean from each variable.
- 2 Dividing each resultant variable by its sample standard deviation.

Use the `zscore` function to perform this standardization.

Compare Handwritten Shapes

In this example, use Procrustes analysis to compare two handwritten number threes. Visually and analytically explore the effects of forcing size and reflection changes as follows:

- “Step 1: Load and Display the Original Data” on page 10-16
- “Step 2: Calculate the Best Transformation” on page 10-17
- “Step 3: Examine the Similarity of the Two Shapes” on page 10-18
- “Step 4: Restrict the Form of the Transformations” on page 10-20

Step 1: Load and Display the Original Data

Input landmark data for two handwritten number threes:

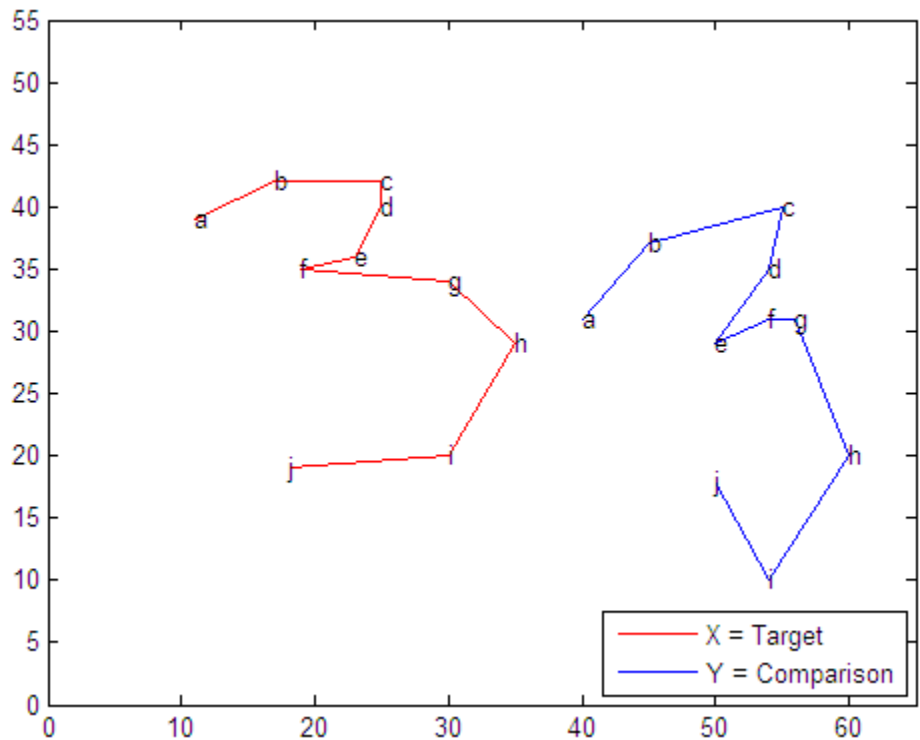
```
A = [11 39;17 42;25 42;25 40;23 36;19 35;30 34;35 29;...  
30 20;18 19];  
B = [15 31;20 37;30 40;29 35;25 29;29 31;31 31;35 20;...  
29 10;25 18];
```

Create X and Y from A and B, moving B to the side to make each shape more visible:

```
X = A;  
Y = B + repmat([25 0], 10,1);
```

Plot the shapes, using letters to designate the landmark points. Lines in the figure join the points to indicate the drawing path of each shape.

```
plot(X(:,1), X(:,2), 'r-', Y(:,1), Y(:,2), 'b-');  
text(X(:,1), X(:,2), ('abcdefghij'))  
text(Y(:,1), Y(:,2), ('abcdefghij'))  
legend('X = Target', 'Y = Comparison', 'location', 'SE')  
set(gca, 'YLim', [0 55], 'XLim', [0 65]);
```



Step 2: Calculate the Best Transformation

Use Procrustes analysis to find the transformation that minimizes distances between landmark data points.

Call `procrustes` as follows:

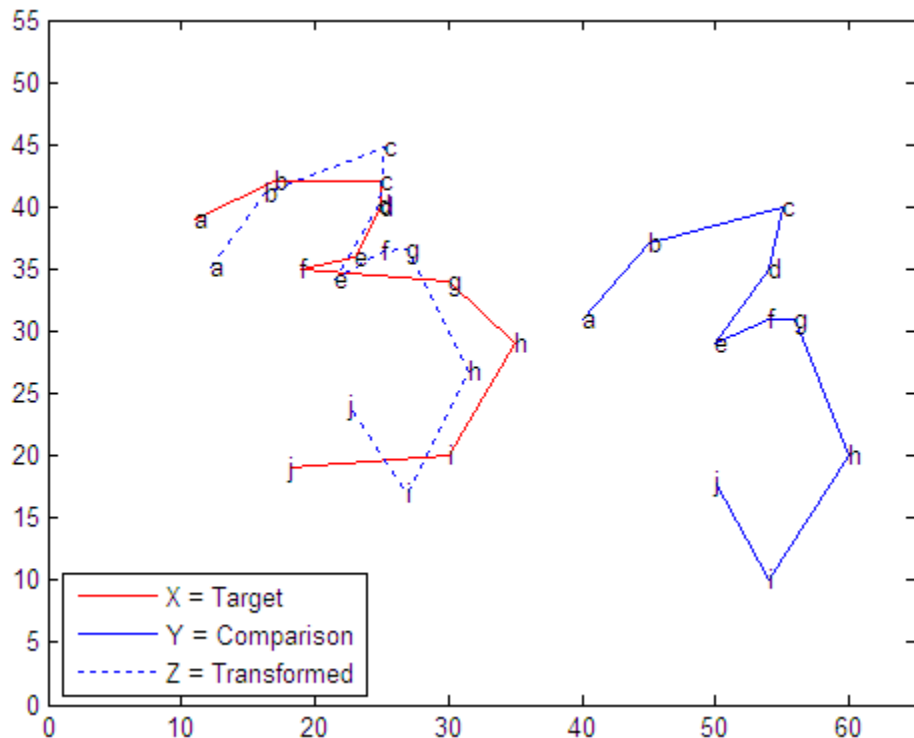
```
[d, Z, tr] = procrustes(X,Y);
```

The outputs of the function are:

- `d` – A standardized dissimilarity measure.)
- `Z` – A matrix of the transformed landmarks.
- `tr` – A structure array of the computed transformation with fields `T`, `b`, and `c` which correspond to the transformation equation, Equation 10-1.

Visualize the transformed shape, Z, using a dashed blue line:

```
plot(X(:,1), X(:,2), 'r-', Y(:,1), Y(:,2), 'b-', ...
     Z(:,1), Z(:,2), 'b:');
text(X(:,1), X(:,2), ('abcdefghij'))
text(Y(:,1), Y(:,2), ('abcdefghij'))
text(Z(:,1), Z(:,2), ('abcdefghij'))
legend('X = Target', 'Y = Comparison', ...
       'Z = Transformed', 'location', 'SW')
set(gca, 'YLim', [0 55], 'XLim', [0 65]);
```



Step 3: Examine the Similarity of the Two Shapes

Use two different numerical values to assess the similarity of the target shape and the transformed shape.

Dissimilarity Measure d. The dissimilarity measure d gives a number between 0 and 1 describing the difference between the target shape and the transformed shape. Values near 0 imply more similar shapes, while values near 1 imply dissimilarity. For this example:

```
d =
    0.1502
```

The small value of d in this case shows that the two shapes are similar.

`procrustes` calculates d by comparing the sum of squared deviations between the set of points with the sum of squared deviations of the original points from their column means:

```
numerator = sum(sum((X-Z).^2))
numerator =

    166.5321

denominator = sum(sum(bsxfun(@minus,X,mean(X)).^2))
denominator =

    1.1085e+003

ratio = numerator/denominator
ratio =

    0.1502
```

Note The resulting measure d is independent of the scale of the size of the shapes and takes into account only the similarity of landmark data. “Examine the Scaling Measure b ” on page 10-19 shows how to examine the size similarity of the shapes.

Examine the Scaling Measure b . The target and comparison threes in the previous figure visually show that the two numbers are of a similar size. The closeness of calculated value of the scaling factor b to 1 supports this observation as well:

```
tr.b
ans =
    0.9291
```

The sizes of the target and comparison shapes appear similar. This visual impression is reinforced by the value of $b = 0.93$, which implies that the best transformation results in shrinking the comparison shape by a factor .93 (only 7%).

Step 4: Restrict the Form of the Transformations

Explore the effects of manually adjusting the scaling and reflection coefficients.

Fix the Scaling Factor $b = 1$. Force b to equal 1 (set 'Scaling' to false) to examine the amount of dissimilarity in size of the target and transformed figures:

```
ds = procrustes(X,Y,'Scaling',false)
ds =
    0.1552
```

In this case, setting 'Scaling' to false increases the calculated value of d only 0.0049, which further supports the similarity in the size of the two number threes. A larger increase in d would have indicated a greater size discrepancy.

Force a Reflection in the Transformation. This example requires only a rotation, not a reflection, to align the shapes. You can show this by observing that the determinant of the matrix T is 1 in this analysis:

```
det(tr.T)
ans =
    1.0000
```

If you need a reflection in the transformation, the determinant of T is -1. You can force a reflection into the transformation as follows:

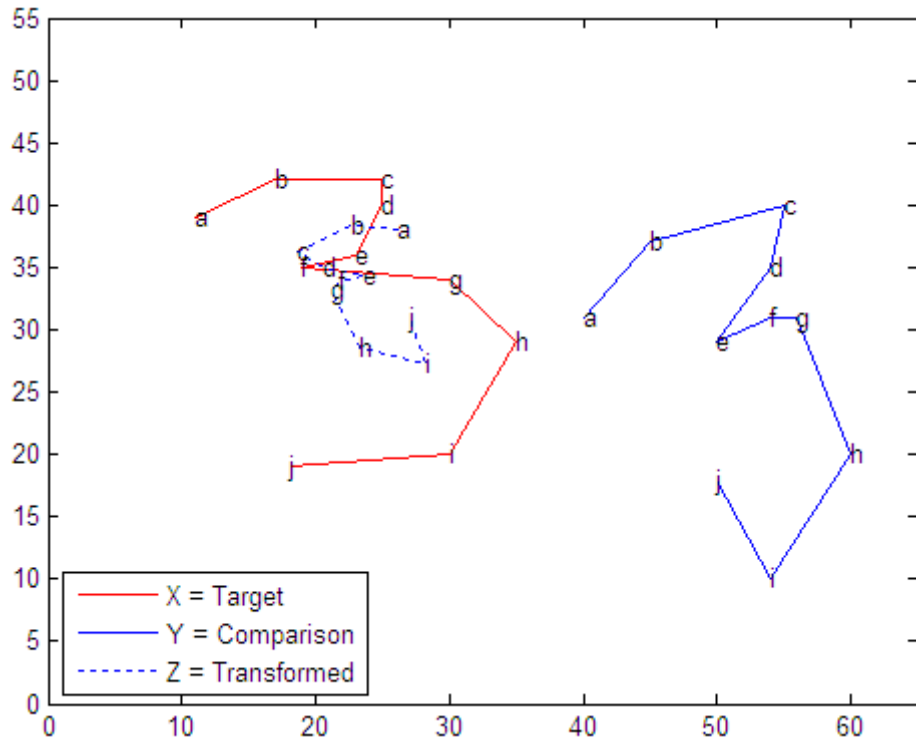
```
[dr,Zr,trr] = procrustes(X,Y,'Reflection',true);
dr
dr =
```


0.8130

The d value increases dramatically, indicating that a forced reflection leads to a poor transformation of the landmark points. A plot of the transformed shape shows a similar result:

- The landmark data points are now further away from their target counterparts.
- The transformed three is now an undesirable mirror image of the target three.

```
plot(X(:,1), X(:,2), 'r-', Y(:,1), Y(:,2), 'b-', ...  
Zr(:,1), Zr(:,2), 'b:');  
text(X(:,1), X(:,2), ('abcdefghij'))  
text(Y(:,1), Y(:,2), ('abcdefghij'))  
text(Zr(:,1), Zr(:,2), ('abcdefghij'))  
legend('X = Target', 'Y = Comparison', ...  
'Z = Transformed', 'location', 'SW')  
set(gca, 'YLim', [0 55], 'XLim', [0 65]);
```



It appears that the shapes might be better matched if you flipped the transformed shape upside down. Flipping the shapes would make the transformation even worse, however, because the landmark data points would be further away from their target counterparts. From this example, it is clear that manually adjusting the scaling and reflection parameters is generally not optimal.

Feature Selection

In this section...
“Introduction to Feature Selection” on page 10-23
“Sequential Feature Selection” on page 10-23

Introduction to Feature Selection

Feature selection reduces the dimensionality of data by selecting only a subset of measured features (predictor variables) to create a model. Selection criteria usually involve the minimization of a specific measure of predictive error for models fit to different subsets. Algorithms search for a subset of predictors that optimally model measured responses, subject to constraints such as required or excluded features and the size of the subset.

Feature selection is preferable to feature transformation when the original units and meaning of features are important and the modeling goal is to identify an influential subset. When categorical features are present, and numerical transformations are inappropriate, feature selection becomes the primary means of dimension reduction.

Sequential Feature Selection

- “Introduction to Sequential Feature Selection” on page 10-23
- “Example: Sequential Feature Selection” on page 10-24

Introduction to Sequential Feature Selection

A common method of feature selection is *sequential feature selection*. This method has two components:

- An objective function, called the *criterion*, which the method seeks to minimize over all feasible feature subsets. Common criteria are mean squared error (for regression models) and misclassification rate (for classification models).
- A sequential search algorithm, which adds or removes features from a candidate subset while evaluating the criterion. Since an exhaustive

comparison of the criterion value at all 2^n subsets of an n -feature data set is typically infeasible (depending on the size of n and the cost of objective calls), sequential searches move in only one direction, always growing or always shrinking the candidate set.

The method has two variants:

- *Sequential forward selection (SFS)*, in which features are sequentially added to an empty candidate set until the addition of further features does not decrease the criterion.
- *Sequential backward selection (SBS)*, in which features are sequentially removed from a full candidate set until the removal of further features increase the criterion.

Stepwise regression is a sequential feature selection technique designed specifically for least-squares fitting. The functions `stepwise` and `stepwisefit` make use of optimizations that are only possible with least-squares criteria. Unlike generalized sequential feature selection, stepwise regression may remove features that have been added or add features that have been removed.

The Statistics Toolbox function `sequentialfs` carries out sequential feature selection. Input arguments include predictor and response data and a function handle to a file implementing the criterion function. Optional inputs allow you to specify SFS or SBS, required or excluded features, and the size of the feature subset. The function calls `cvpartition` and `crossval` to evaluate the criterion at different candidate sets.

Example: Sequential Feature Selection

For example, consider a data set with 100 observations of 10 predictors. The following generates random data from a logistic model, with a binomial distribution of responses at each set of values for the predictors. Some coefficients are set to zero so that not all of the predictors affect the response:

```
n = 100;  
m = 10;  
X = rand(n,m);  
b = [1 0 0 2 .5 0 0 0.1 0 1];  
Xb = X*b';  
p = 1./(1+exp(-Xb));
```

```
N = 50;  
y = binornd(N,p);
```

The `glmfit` function fits a logistic model to the data:

```
Y = [y N*ones(size(y))];  
[b0,dev0,stats0] = glmfit(X,Y,'binomial');
```

% Display coefficient estimates and their standard errors:

```
model0 = [b0 stats0.se]  
model0 =
```

0.3115	0.2596
0.9614	0.1656
-0.1100	0.1651
-0.2165	0.1683
1.9519	0.1809
0.5683	0.2018
-0.0062	0.1740
0.0651	0.1641
-0.1034	0.1685
0.0017	0.1815
0.7979	0.1806

% Display the deviance of the fit:

```
dev0  
dev0 =  
101.2594
```

This is the full model, using all of the features (and an initial constant term). Sequential feature selection searches for a subset of the features in the full model with comparative predictive power.

First, you must specify a criterion for selecting the features. The following function, which calls `glmfit` and returns the deviance of the fit (a generalization of the residual sum of squares) is a useful criterion in this case:

```
function dev = critfun(X,Y)  
  
[b,dev] = glmfit(X,Y,'binomial');
```

You should create this function as a file on the MATLAB path.

The function `sequentialfs` performs feature selection, calling the criterion function via a function handle:

```
maxdev = chi2inv(.95,1);
opt = statset('display','iter',...
             'TolFun',maxdev,...
             'TolTypeFun','abs');

inmodel = sequentialfs(@critfun,X,Y,...
                      'cv','none',...
                      'nullmodel',true,...
                      'options',opt,...
                      'direction','forward');
```

Start forward sequential feature selection:

```
Initial columns included: none
Columns that can not be included: none
Step 1, used initial columns, criterion value 309.118
Step 2, added column 4, criterion value 180.732
Step 3, added column 1, criterion value 138.862
Step 4, added column 10, criterion value 114.238
Step 5, added column 5, criterion value 103.503
Final columns included: 1 4 5 10
```

The iterative display shows a decrease in the criterion value as each new feature is added to the model. The final result is a reduced model with only four of the original ten features: columns 1, 4, 5, and 10 of X . These features are indicated in the logical vector `inmodel` returned by `sequentialfs`.

The deviance of the reduced model is higher than for the full model, but the addition of any other single feature would not decrease the criterion by more than the absolute tolerance, `maxdev`, set in the options structure. Adding a feature with no effect reduces the deviance by an amount that has a chi-square distribution with one degree of freedom. Adding a significant feature results in a larger change. By setting `maxdev` to `chi2inv(.95,1)`, you instruct `sequentialfs` to continue adding features so long as the change in deviance is more than would be expected by random chance.

The reduced model (also with an initial constant term) is:

```
[b,dev,stats] = glmfit(X(:,inmodel),Y,'binomial');
```

```
% Display coefficient estimates and their standard errors:  
model = [b stats.se]  
model =  
    0.0784    0.1642  
    1.0040    0.1592  
    1.9459    0.1789  
    0.6134    0.1872  
    0.8245    0.1730
```

Feature Transformation

In this section...

“Introduction to Feature Transformation” on page 10-28

“Nonnegative Matrix Factorization” on page 10-28

“Principal Component Analysis (PCA)” on page 10-31

“Quality of Life in U.S. Cities” on page 10-33

“Factor Analysis” on page 10-45

Introduction to Feature Transformation

Feature transformation is a group of methods that create new features (predictor variables). The methods are useful for dimension reduction when the transformed features have a descriptive power that is more easily ordered than the original features. In this case, less descriptive features can be dropped from consideration when building models.

Feature transformation methods are contrasted with the methods presented in “Feature Selection” on page 10-23, where dimension reduction is achieved by computing an optimal subset of predictive features measured in the original data.

The methods presented in this section share some common methodology. Their goals, however, are essentially different:

- Nonnegative matrix factorization is used when model terms must represent nonnegative quantities, such as physical quantities.
- Principal component analysis is used to summarize data in fewer dimensions, for example, to visualize it.
- Factor analysis is used to build explanatory models of data correlations.

Nonnegative Matrix Factorization

- “Introduction to Nonnegative Matrix Factorization” on page 10-29
- “Example: Nonnegative Matrix Factorization” on page 10-29

Introduction to Nonnegative Matrix Factorization

Nonnegative matrix factorization (NMF) is a dimension-reduction technique based on a low-rank approximation of the feature space. Besides providing a reduction in the number of features, NMF guarantees that the features are nonnegative, producing additive models that respect, for example, the nonnegativity of physical quantities.

Given a nonnegative m -by- n matrix X and a positive integer $k < \min(m, n)$, NMF finds nonnegative m -by- k and k -by- n matrices W and H , respectively, that minimize the norm of the difference $X - WH$. W and H are thus approximate nonnegative factors of X .

The k columns of W represent transformations of the variables in X ; the k rows of H represent the coefficients of the linear combinations of the original n variables in X that produce the transformed variables in W . Since k is generally smaller than the rank of X , the product WH provides a compressed approximation of the data in X . A range of possible values for k is often suggested by the modeling context.

The Statistics Toolbox function `nnmf` carries out nonnegative matrix factorization. `nnmf` uses one of two iterative algorithms that begin with random initial values for W and H . Because the norm of the residual $X - WH$ may have local minima, repeated calls to `nnmf` may yield different factorizations. Sometimes the algorithm converges to a solution of lower rank than k , which may indicate that the result is not optimal.

Example: Nonnegative Matrix Factorization

For example, consider the five predictors of biochemical oxygen demand in the data set `moore.mat`:

```
load moore
X = moore(:,1:5);
```

The following uses `nnmf` to compute a rank-two approximation of X with a multiplicative update algorithm that begins from five random initial values for W and H :

```
opt = statset('MaxIter',10,'Display','final');
[WO,H0] = nnmf(X,2,'replicates',5,...
               'options',opt,...
```

```

                                'algorithm','mult');
rep iteration      rms resid    |delta x|
  1      10        358.296     0.00190554
  2      10         78.3556    0.000351747
  3      10        230.962     0.0172839
  4      10        326.347     0.00739552
  5      10        361.547     0.00705539
Final root mean square residual = 78.3556

```

The 'mult' algorithm is sensitive to initial values, which makes it a good choice when using 'replicates' to find W and H from multiple random starting values.

Now perform the factorization using an alternating least-squares algorithm, which converges faster and more consistently. Run 100 times more iterations, beginning from the initial W0 and H0 identified above:

```

opt = statset('Maxiter',1000,'Display','final');
[W,H] = nnmf(X,2,'w0',W0,'h0',H0,...
             'options',opt,...
             'algorithm','als');
rep iteration      rms resid    |delta x|
  1          3         77.5315  3.52673e-005
Final root mean square residual = 77.5315

```

The two columns of W are the transformed predictors. The two rows of H give the relative contributions of each of the five predictors in X to the predictors in W:

```

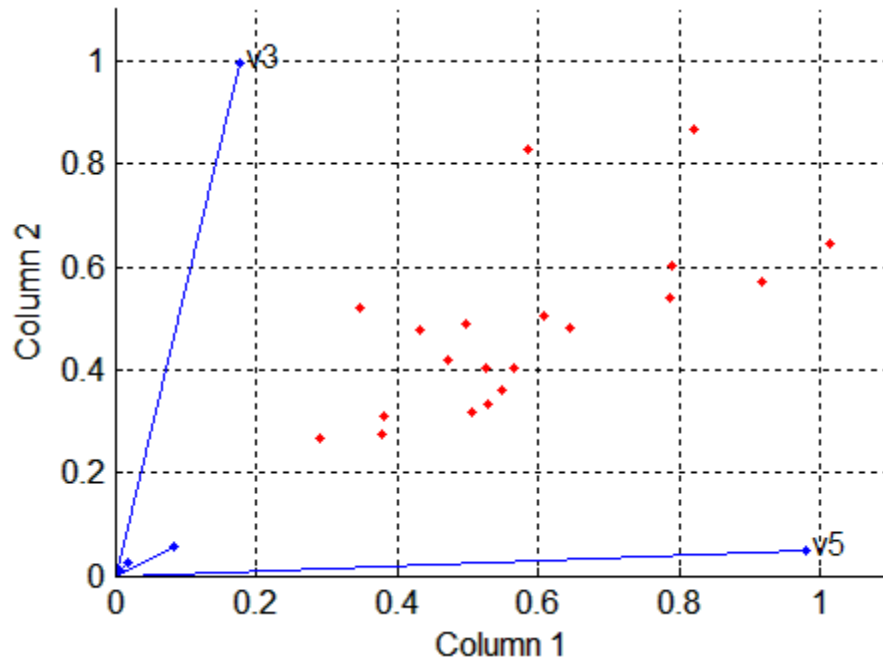
H
H =
    0.0835    0.0190    0.1782    0.0072    0.9802
    0.0558    0.0250    0.9969    0.0085    0.0497

```

The fifth predictor in X (weight 0.9802) strongly influences the first predictor in W. The third predictor in X (weight 0.9969) strongly influences the second predictor in W.

Visualize the relative contributions of the predictors in X with a biplot, showing the data and original variables in the column space of W:

```
biplot(H,'scores',W,'varlabels',{' ',' ','v3',' ','v5'});
axis([0 1.1 0 1.1])
xlabel('Column 1')
ylabel('Column 2')
```



Principal Component Analysis (PCA)

One of the difficulties inherent in multivariate statistics is the problem of visualizing data that has many variables. The MATLAB function `plot` displays a graph of the relationship between two variables. The `plot3` and `surf` commands display different three-dimensional views. But when there are more than three variables, it is more difficult to visualize their relationships.

Fortunately, in data sets with many variables, groups of variables often move together. One reason for this is that more than one variable might be measuring the same driving principle governing the behavior of the system. In many systems there are only a few such driving forces. But an abundance

of instrumentation enables you to measure dozens of system variables. When this happens, you can take advantage of this redundancy of information. You can simplify the problem by replacing a group of variables with a single new variable.

Principal component analysis is a quantitatively rigorous method for achieving this simplification. The method generates a new set of variables, called *principal components*. Each principal component is a linear combination of the original variables. All the principal components are orthogonal to each other, so there is no redundant information. The principal components as a whole form an orthogonal basis for the space of the data.

There are an infinite number of ways to construct an orthogonal basis for several columns of data. What is so special about the principal component basis?

The first principal component is a single axis in space. When you project each observation on that axis, the resulting values form a new variable. And the variance of this variable is the maximum among all possible choices of the first axis.

The second principal component is another axis in space, perpendicular to the first. Projecting the observations on this axis generates another new variable. The variance of this variable is the maximum among all possible choices of this second axis.

The full set of principal components is as large as the original set of variables. But it is commonplace for the sum of the variances of the first few principal components to exceed 80% of the total variance of the original data. By examining plots of these few new variables, researchers often develop a deeper understanding of the driving forces that generated the original data.

You can use the function `pca` to find the principal components. To use `pca`, you need to have the actual measured data you want to analyze. However, if you lack the actual data, but have the sample covariance or correlation matrix for the data, you can still use the function `pcacov` to perform a principal components analysis. See the reference page for `pcacov` for a description of its inputs and outputs.

Quality of Life in U.S. Cities

This example shows how to perform a weighted principal components analysis and interpret the results.

Explore data.

Load the sample data.

```
load cities
```

The data includes ratings for 9 different indicators of the quality of life in 329 U.S. cities. These are climate, housing, health, crime, transportation, education, arts, recreation, and economics. For each category, a higher rating is better. For example, a higher rating for crime means a lower crime rate.

The `cities` data set contains three variables:

- `categories`, a string matrix containing the names of the indices
- `names`, a string matrix containing the 329 city names
- `ratings`, the data matrix with 329 rows and 9 columns

Display the `categories` variable.

```
categories
```

```
categories =  
  climate  
  housing  
  health  
  crime  
  transportation  
  education  
  arts  
  recreation  
  economics
```

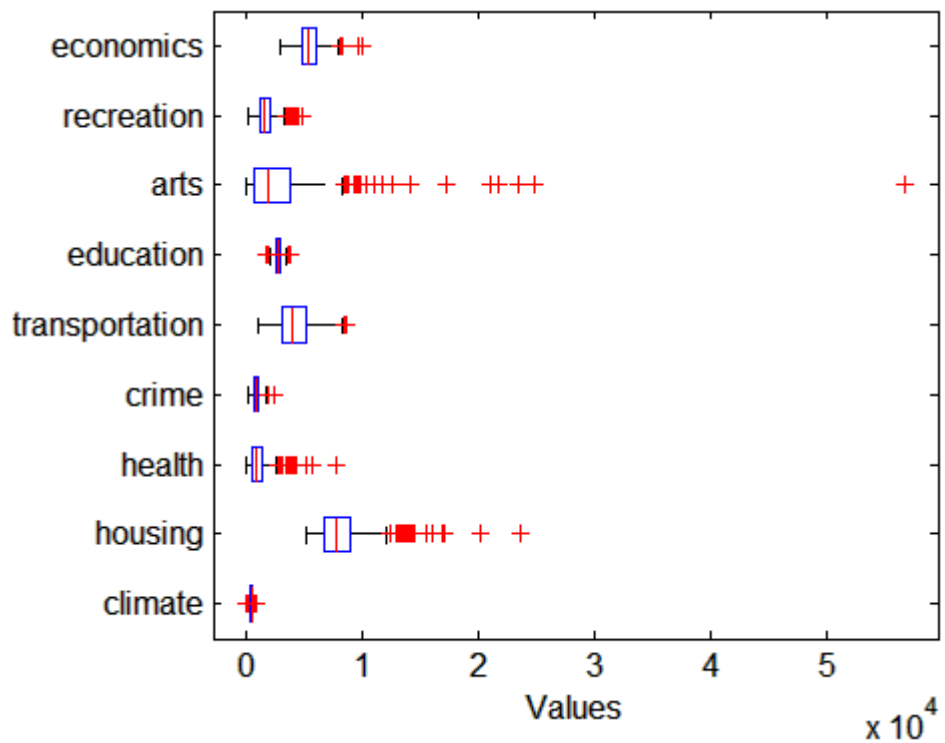
Display the first five rows of the `names` variable.

```
first5 = names(1:5,:)
```

```
first5 =
  Abilene, TX
  Akron, OH
  Albany, GA
  Albany-Troy, NY
  Albuquerque, NM
```

Make a boxplot to look at the distribution of the ratings data.

```
figure()
boxplot(ratings,'orientation','horizontal','labels',categories)
```



There is more variability in the ratings of the arts and housing than in the ratings of crime and climate.

Now, check the pairwise correlation between the variables.

```
C = corr(ratings,ratings);
```

The correlation among some variables is as high as 0.85. Principal components analysis constructs independent new variables which are linear combinations of the original variables.

Compute principal components.

When all variables are in the same unit, it is appropriate to compute principal components for raw data. When the variables are in different units or the difference in the variance of different columns is substantial (as in this case), scaling of the data or use of weights is often preferable.

Perform the principal component analysis by using the inverse variances of the ratings as weights.

```
w = 1./var(ratings);
[wcoeff,score,latent,tsquared,explained] = pca(ratings,...
'VariableWeights',w);
```

Or equivalently:

```
[wcoeff,score,latent,tsquared,explained] = pca(ratings,...
'VariableWeights','variance');
```

The following sections explain the five outputs of `pca`.

Component coefficients.

The first output, `wcoeff`, contains the coefficients of the principal components.

The first three principal component coefficient vectors are:

```
c3 = wcoeff(:,1:3)
```

```
c3 = wcoeff(:,1:3)
c3 =
```

```
1.0e+03 *
```

```
0.0249 -0.0263 -0.0834
0.8504 -0.5978 -0.4965
0.4616 0.3004 -0.0073
0.1005 -0.1269 0.0661
0.5096 0.2606 0.2124
0.0883 0.1551 0.0737
2.1496 0.9043 -0.1229
0.2649 -0.3106 -0.0411
0.1469 -0.5111 0.6586
```

These coefficients are weighted, hence the coefficient matrix is not orthonormal.

Compute the orthonormal coefficient matrix.

```
coefforth = inv(diag(std(ratings)))*wcoeff;
```

Or if you use a weights vector, w , while conducting the `pca`, then

```
coefforth = diag(sqrt(w))*wcoeff;
```

The first three transformed coefficients are:

```
c3 = coefforth(:,1:3)
```

```
c3 =
```

```
0.2064 -0.2178 -0.6900
0.3565 -0.2506 -0.2082
0.4602 0.2995 -0.0073
0.2813 -0.3553 0.1851
0.3512 0.1796 0.1464
0.2753 0.4834 0.2297
0.4631 0.1948 -0.0265
0.3279 -0.3845 -0.0509
0.1354 -0.4713 0.6073
```

The transformed coefficients are now orthonormal.

```
I = c3'*c3
```



```
I =  
    1.0000    -0.0000    -0.0000  
   -0.0000     1.0000    -0.0000  
   -0.0000    -0.0000     1.0000
```

Component scores.

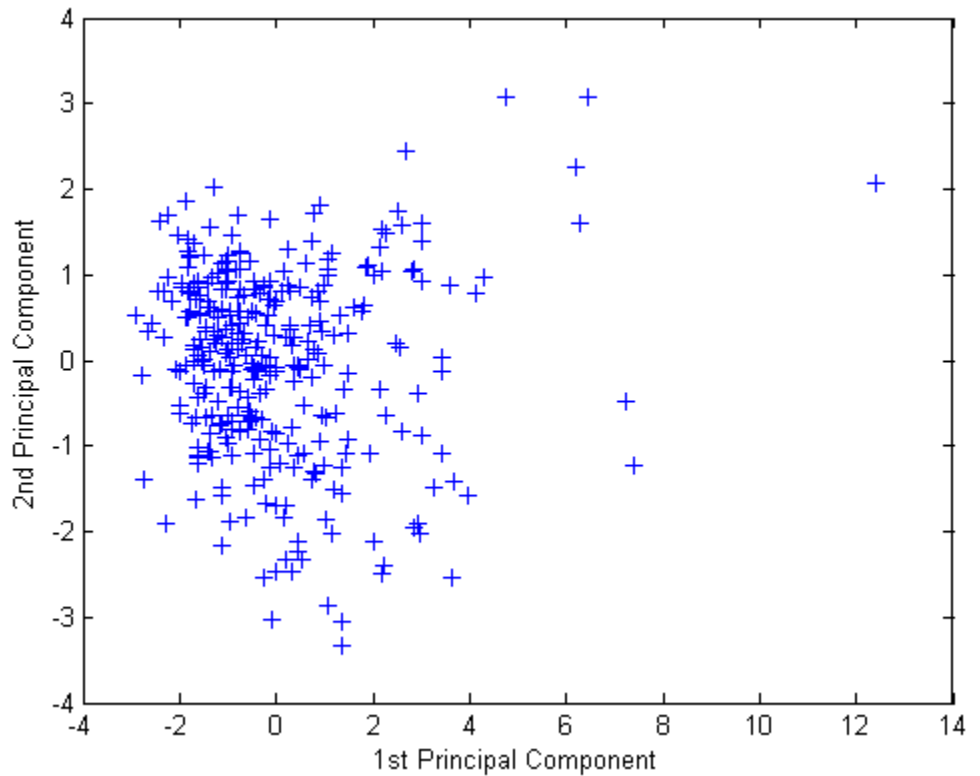
The second output, `score`, contains the coordinates of the original data in the new coordinate system defined by the principal components. The `score` matrix is the same size as the input data matrix. You can also obtain the component scores using the orthonormal coefficients and the standardized ratings as follows.

```
cscores = zscore(ratings)*coefforth;
```

`cscores` and `score` are identical matrices.

Create a plot of the first two columns of `score`.

```
figure()  
plot(score(:,1),score(:,2),'+')  
xlabel('1st Principal Component')  
ylabel('2nd Principal Component')
```

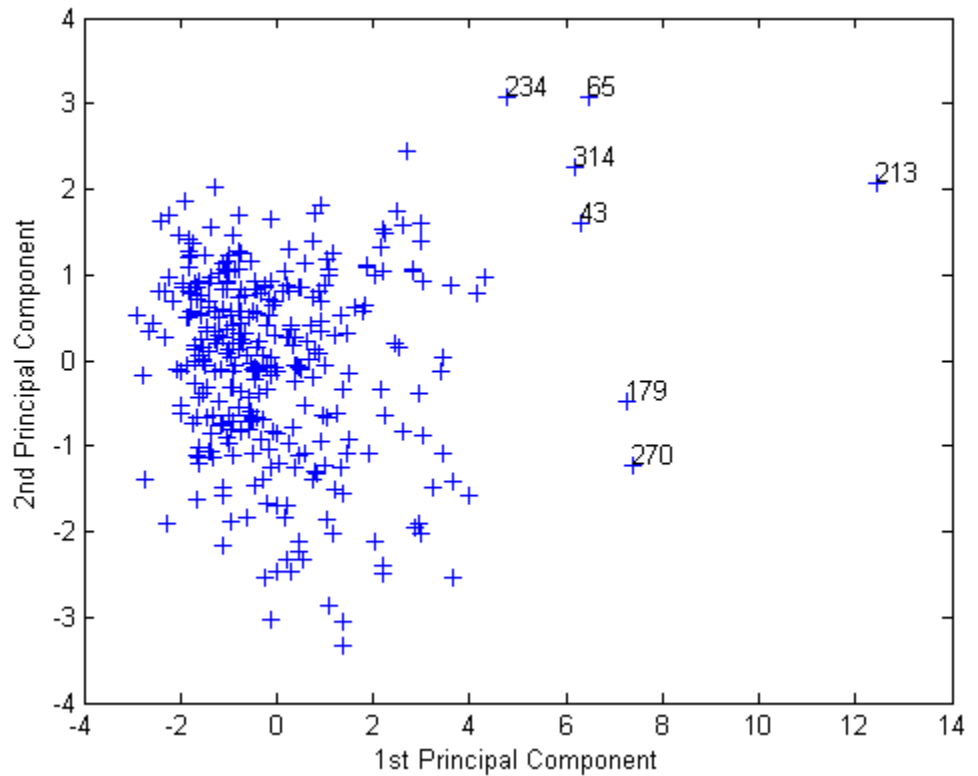


This plot shows the centered and scaled ratings data projected onto the first two principal components. `pca` computes the scores to have mean zero.

Note the outlying points in the right half of the plot. You can graphically identify these points as follows.

```
gname
```

Move your cursor over the plot and click once near the rightmost seven points. This labels the points by their row numbers as in the following figure.



After labeling points, press **Return**.

Create an index variable containing the row numbers of all the cities you chose and get the names of the cities.

```
metro = [43 65 179 213 234 270 314];
names(metro,:)
```

```
ans =
    Boston, MA
    Chicago, IL
    Los Angeles, Long Beach, CA
    New York, NY
```

```
Philadelphia, PA-NJ  
San Francisco, CA  
Washington, DC-MD-VA
```

These labeled cities are some of the biggest population centers in the United States and they appear more extreme than the remainder of the data.

Component variances and percent explained.

The third output, `latent`, is a vector containing the variance explained by the corresponding principal component. Each column of `score` has a sample variance equal to the corresponding row of `latent`.

```
latent
```

```
latent =
```

```
3.4083  
1.2140  
1.1415  
0.9209  
0.7533  
0.6306  
0.4930  
0.3180  
0.1204
```

The fifth output, `explained`, is a vector containing the percent variance explained by the corresponding principal component.

```
explained
```

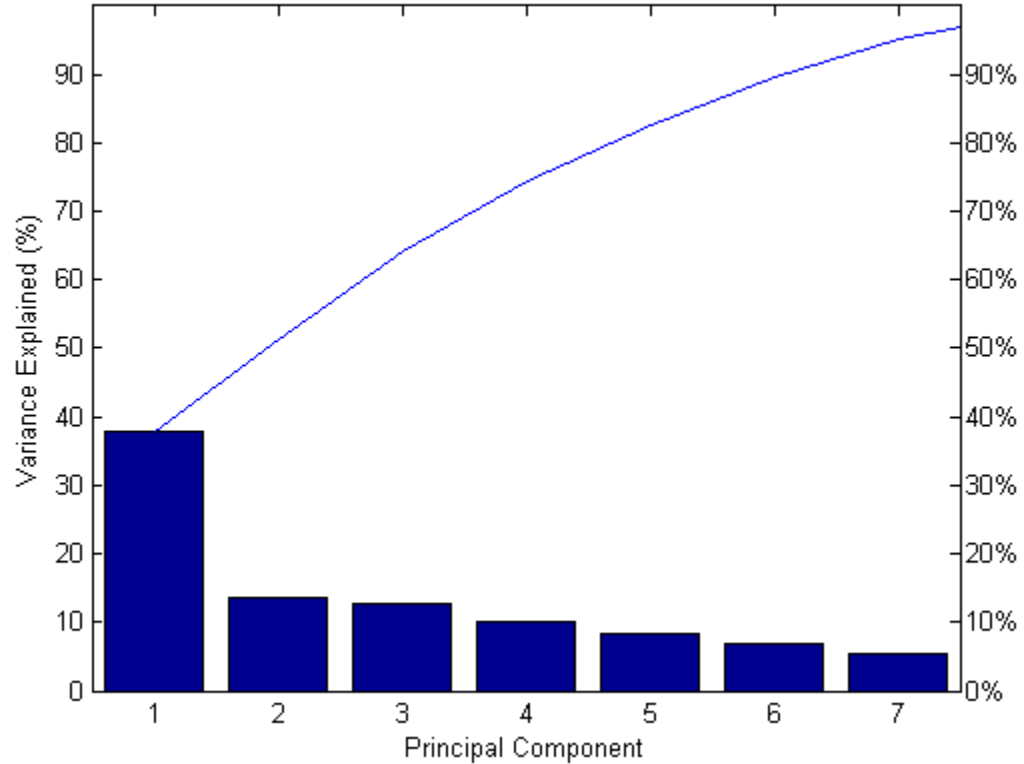
```
explained =
```

```
37.8699  
13.4886  
12.6831  
10.2324  
8.3698  
7.0062  
5.4783
```

```
3.5338
1.3378
```

Make a scree plot of the percent variability explained by each principal component.

```
figure()
pareto(explained)
xlabel('Principal Component')
ylabel('Variance Explained (%)')
```



This scree plot only shows the first seven (instead of the total nine) components that explain 95% of the total variance. The only clear break in

the amount of variance accounted for by each component is between the first and second components. However, the first component by itself explains less than 40% of the variance, so more components might be needed. You can see that the first three principal components explain roughly two-thirds of the total variability in the standardized ratings, so that might be a reasonable way to reduce the dimensions.

Hotelling's T-squared statistic.

The last output of `pca` is `tsquared`, which is Hotelling's T^2 , a statistical measure of the multivariate distance of each observation from the center of the data set. This is an analytical way to find the most extreme points in the data.

```
[st2,index] = sort(tsquared,'descend'); % sort in descending order
extreme = index(1)
```

```
extreme =
```

```
213
```

```
names(extreme,:)
```

```
ans =
```

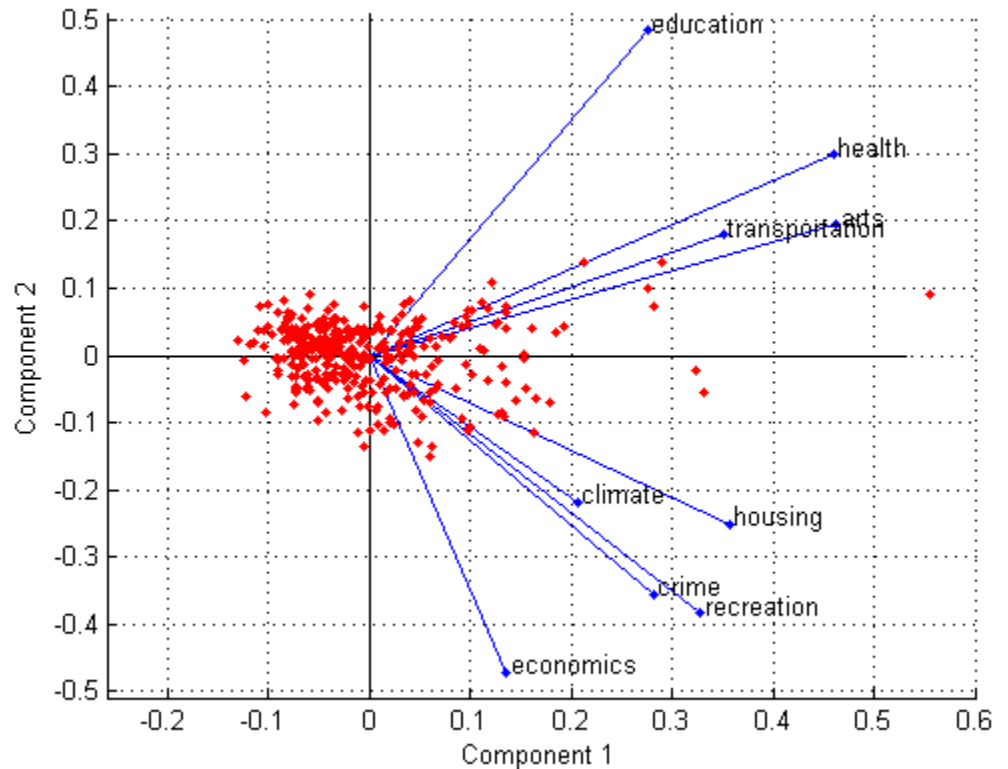
```
New York, NY
```

The ratings for New York are the furthest from the average U.S. city.

Visualize the results.

Visualize both the orthonormal principal component coefficients for each variable and the principal component scores for each observation in a single plot.

```
biplot(coefforth(:,1:2), 'scores', score(:,1:2), 'varlabels', categories);
axis([-0.26 0.6 -0.51 0.51]);
```



All nine variables are represented in this bi-plot by a vector, and the direction and length of the vector indicate how each variable contributes to the two principal components in the plot. For example, the first principal component, on the horizontal axis, has positive coefficients for all nine variables. That is why the nine vectors are directed into the right half of the plot. The largest coefficients in the first principal component are the third and seventh elements, corresponding to the variables `health` and `arts`.

The second principal component, on the vertical axis, has positive coefficients for the variables `education`, `health`, `arts`, and `transportation`, and negative coefficients for the remaining five variables. This indicates that the

second component distinguishes among cities that have high values for the first set of variables and low for the second, and cities that have the opposite.

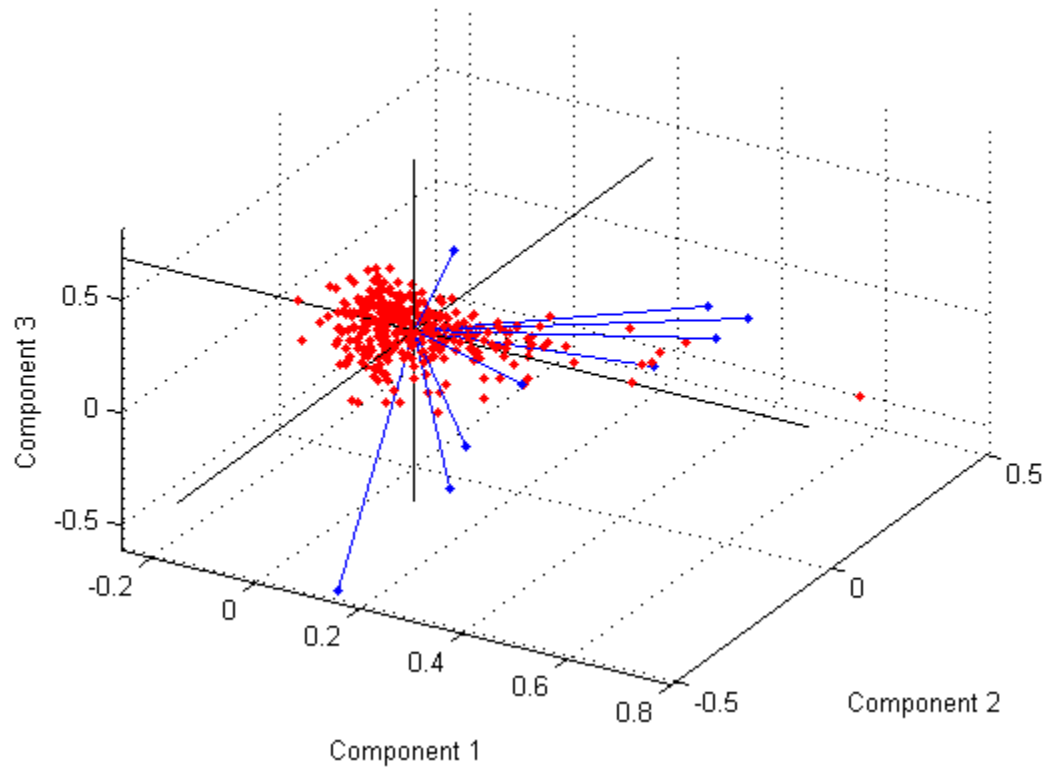
The variable labels in this figure are somewhat crowded. You can either exclude the `VarLabels` parameter when making the plot, or select and drag some of the labels to better positions using the Edit Plot tool from the figure window toolbar.

This 2-D bi-plot also includes a point for each of the 329 observations, with coordinates indicating the score of each observation for the two principal components in the plot. For example, points near the left edge of this plot have the lowest scores for the first principal component. The points are scaled with respect to the maximum score value and maximum coefficient length, so only their relative locations can be determined from the plot.

You can identify items in the plot by selecting **Tools>Data Cursor** from the figure window. By clicking a variable (vector), you can read that variable's coefficients for each principal component. By clicking an observation (point), you can read that observation's scores for each principal component.

You can also make a bi-plot in three dimensions.

```
figure()
biplot(coefforth(:,1:3), 'scores', score(:,1:3), 'obslabels', names);
axis([-0.26 0.8 -0.51 0.51 -0.61 0.81]);
view([30 40]);
```

This graph is useful if the first two principal coordinates do not explain enough of the variance in your data. You can also rotate the figure to see it from different angles by selecting the **Tools**> **Rotate 3D**.

Factor Analysis

- “Introduction to Factor Analysis” on page 10-46
- “Example: Factor Analysis” on page 10-46

Introduction to Factor Analysis

Multivariate data often includes a large number of measured variables, and sometimes those variables overlap, in the sense that groups of them might be dependent. For example, in a decathlon, each athlete competes in 10 events, but several of them can be thought of as speed events, while others can be thought of as strength events, etc. Thus, you can think of a competitor's 10 event scores as largely dependent on a smaller set of three or four types of athletic ability.

Factor analysis is a way to fit a model to multivariate data to estimate just this sort of interdependence. In a factor analysis model, the measured variables depend on a smaller number of unobserved (latent) factors. Because each factor might affect several variables in common, they are known as *common factors*. Each variable is assumed to be dependent on a linear combination of the common factors, and the coefficients are known as *loadings*. Each measured variable also includes a component due to independent random variability, known as *specific variance* because it is specific to one variable.

Specifically, factor analysis assumes that the covariance matrix of your data is of the form

$$\Sigma_x = \Lambda\Lambda^T + \Psi$$

where Λ is the matrix of loadings, and the elements of the diagonal matrix Ψ are the specific variances. The function `factoran` fits the Factor Analysis model using maximum likelihood.

Example: Factor Analysis

- “Factor Loadings” on page 10-47
- “Factor Rotation” on page 10-49
- “Factor Scores” on page 10-51
- “Visualize the Results” on page 10-52

Factor Loadings. Over the course of 100 weeks, the percent change in stock prices for ten companies has been recorded. Of the ten companies, the first four can be classified as primarily technology, the next three as financial, and the last three as retail. It seems reasonable that the stock prices for companies that are in the same sector might vary together as economic conditions change. Factor Analysis can provide quantitative evidence that companies within each sector do experience similar week-to-week changes in stock price.

In this example, you first load the data, and then call `factoran`, specifying a model fit with three common factors. By default, `factoran` computes rotated estimates of the loadings to try and make their interpretation simpler. But in this example, you specify an unrotated solution.

```
load stockreturns
```

```
[Loadings,specificVar,T,stats] = ...
    factoran(stocks,3,'rotate','none');
```

The first two `factoran` return arguments are the estimated loadings and the estimated specific variances. Each row of the loadings matrix represents one of the ten stocks, and each column corresponds to a common factor. With unrotated estimates, interpretation of the factors in this fit is difficult because most of the stocks contain fairly large coefficients for two or more factors.

Loadings

```
Loadings =
    0.8885    0.2367   -0.2354
    0.7126    0.3862    0.0034
    0.3351    0.2784   -0.0211
    0.3088    0.1113   -0.1905
    0.6277   -0.6643    0.1478
    0.4726   -0.6383    0.0133
    0.1133   -0.5416    0.0322
    0.6403    0.1669    0.4960
    0.2363    0.5293    0.5770
    0.1105    0.1680    0.5524
```

Note “Factor Rotation” on page 10-49 helps to simplify the structure in the Loadings matrix, to make it easier to assign meaningful interpretations to the factors.

From the estimated specific variances, you can see that the model indicates that a particular stock price varies quite a lot beyond the variation due to the common factors.

```
specificVar
specificVar =
    0.0991
    0.3431
    0.8097
    0.8559
    0.1429
    0.3691
    0.6928
    0.3162
    0.3311
    0.6544
```

A specific variance of 1 would indicate that there is *no* common factor component in that variable, while a specific variance of 0 would indicate that the variable is *entirely* determined by common factors. These data seem to fall somewhere in between.

The p value returned in the `stats` structure fails to reject the null hypothesis of three common factors, suggesting that this model provides a satisfactory explanation of the covariation in these data.

```
stats.p
ans =
    0.8144
```

To determine whether fewer than three factors can provide an acceptable fit, you can try a model with two common factors. The p value for this second fit is highly significant, and rejects the hypothesis of two factors, indicating that the simpler model is not sufficient to explain the pattern in these data.

```
[Loadings2,specificVar2,T2,stats2] = ...
    factoran(stocks, 2,'rotate','none');
```

```
stats2.p
ans =
    3.5610e-006
```

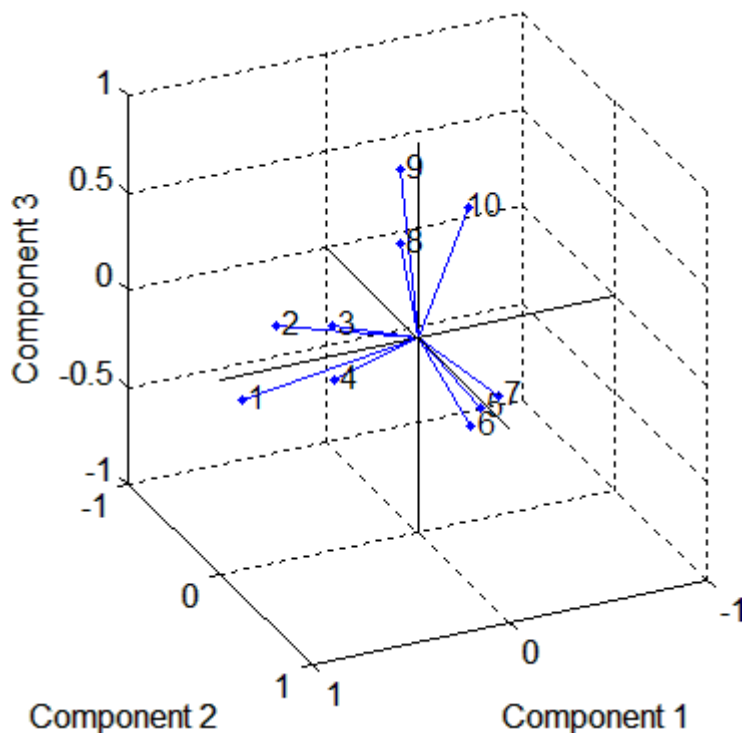
Factor Rotation. As the results illustrate, the estimated loadings from an unrotated factor analysis fit can have a complicated structure. The goal of factor rotation is to find a parameterization in which each variable has only a small number of large loadings. That is, each variable is affected by a small number of factors, preferably only one. This can often make it easier to interpret what the factors represent.

If you think of each row of the loadings matrix as coordinates of a point in M -dimensional space, then each factor corresponds to a coordinate axis. Factor rotation is equivalent to rotating those axes and computing new loadings in the rotated coordinate system. There are various ways to do this. Some methods leave the axes orthogonal, while others are oblique methods that change the angles between them. For this example, you can rotate the estimated loadings by using the promax criterion, a common oblique method.

```
[LoadingsPM,specVarPM] = factoran(stocks,3,'rotate','promax');
LoadingsPM
LoadingsPM =
    0.9452    0.1214   -0.0617
    0.7064   -0.0178    0.2058
    0.3885   -0.0994    0.0975
    0.4162   -0.0148   -0.1298
    0.1021    0.9019    0.0768
    0.0873    0.7709   -0.0821
   -0.1616    0.5320   -0.0888
    0.2169    0.2844    0.6635
    0.0016   -0.1881    0.7849
   -0.2289    0.0636    0.6475
```

Promax rotation creates a simpler structure in the loadings, one in which most of the stocks have a large loading on only one factor. To see this structure more clearly, you can use the `biplot` function to plot each stock using its factor loadings as coordinates.

```
biplot(LoadingsPM, 'varlabels', num2str((1:10)'));  
axis square  
view(155,27);
```



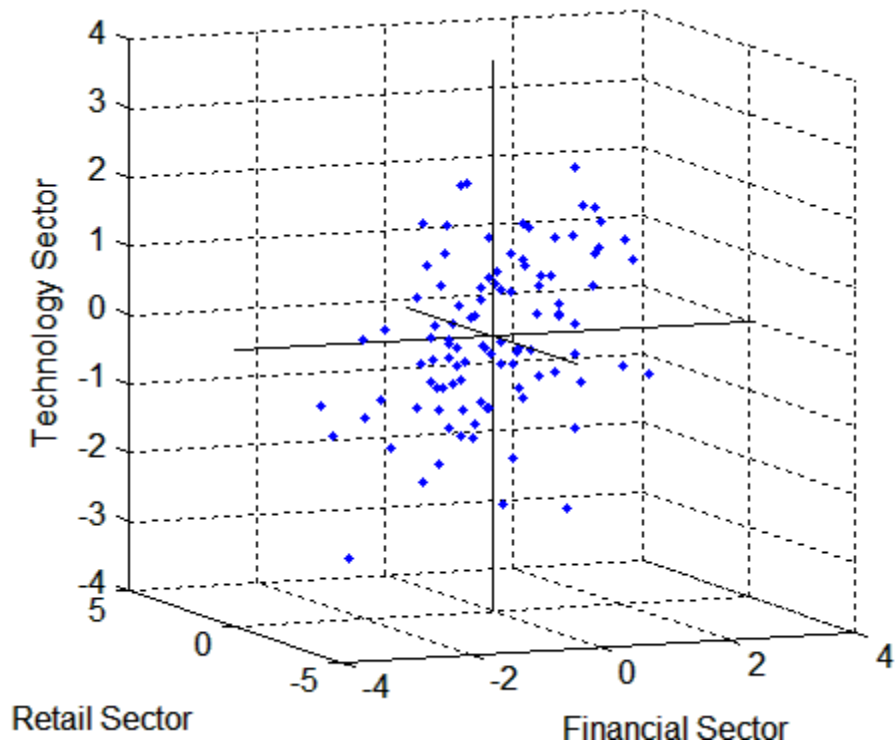
This plot shows that promax has rotated the factor loadings to a simpler structure. Each stock depends primarily on only one factor, and it is possible to describe each factor in terms of the stocks that it affects. Based on which companies are near which axes, you could reasonably conclude that the first factor axis represents the financial sector, the second retail, and the third technology. The original conjecture, that stocks vary primarily within sector, is apparently supported by the data.

Factor Scores. Sometimes, it is useful to be able to classify an observation based on its factor scores. For example, if you accepted the three-factor model and the interpretation of the rotated factors, you might want to categorize each week in terms of how favorable it was for each of the three stock sectors, based on the data from the 10 observed stocks.

Because the data in this example are the raw stock price changes, and not just their correlation matrix, you can have `factoran` return estimates of the value of each of the three rotated common factors for each week. You can then plot the estimated scores to see how the different stock sectors were affected during each week.

```
[LoadingsPM,specVarPM,TPM,stats,F] = ...
    factoran(stocks, 3,'rotate','promax');

plot3(F(:,1),F(:,2),F(:,3),'b.')
line([-4 4 NaN 0 0 NaN 0 0], [0 0 NaN -4 4 NaN 0 0],...
     [0 0 NaN 0 0 NaN -4 4], 'Color','black')
xlabel('Financial Sector')
ylabel('Retail Sector')
zlabel('Technology Sector')
grid on
axis square
view(-22.5, 8)
```



Oblique rotation often creates factors that are correlated. This plot shows some evidence of correlation between the first and third factors, and you can investigate further by computing the estimated factor correlation matrix.

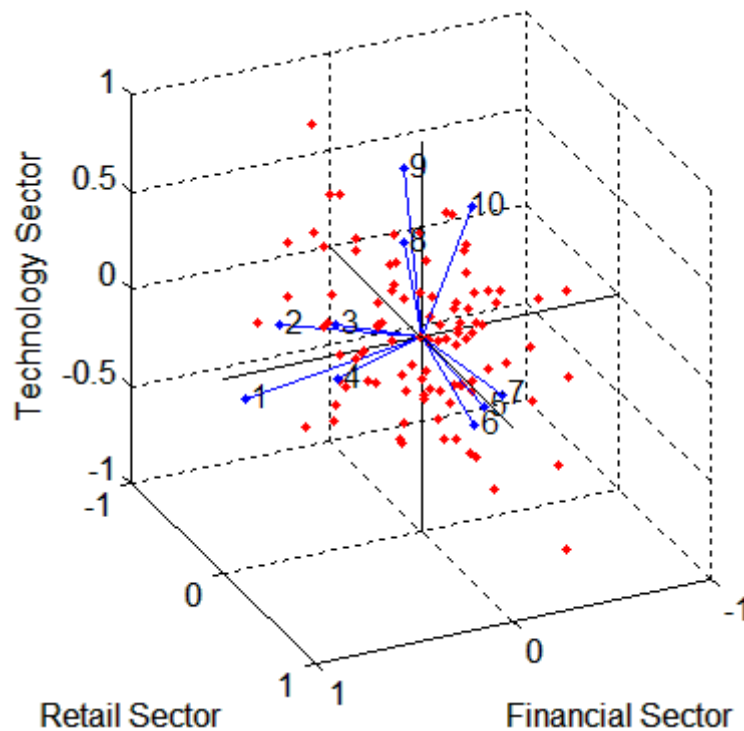
```
inv(TPM' * TPM)
ans =
    1.0000    0.1559    0.4082
    0.1559    1.0000   -0.0559
    0.4082   -0.0559    1.0000
```

Visualize the Results. You can use the `biplot` function to help visualize both the factor loadings for each variable and the factor scores for each observation in a single plot. For example, the following command plots the results from the factor analysis on the stock data and labels each of the 10 stocks.


```

biplot(LoadingsPM,'scores',F,'varlabels',num2str((1:10)))
xlabel('Financial Sector')
ylabel('Retail Sector')
zlabel('Technology Sector')
axis square
view(155,27)

```



In this case, the factor analysis includes three factors, and so the biplot is three-dimensional. Each of the 10 stocks is represented in this plot by a vector, and the direction and length of the vector indicates how each stock depends on the underlying factors. For example, you have seen that after promax rotation, the first four stocks have positive loadings on the first factor, and unimportant loadings on the other two factors. That first factor, interpreted as a financial sector effect, is represented in this biplot as one of the horizontal axes. The dependence of those four stocks on that factor corresponds to the four vectors directed approximately along that axis. Similarly, the dependence

of stocks 5, 6, and 7 primarily on the second factor, interpreted as a retail sector effect, is represented by vectors directed approximately along that axis.

Each of the 100 observations is represented in this plot by a point, and their locations indicate the score of each observation for the three factors. For example, points near the top of this plot have the highest scores for the technology sector factor. The points are scaled to fit within the unit square, so only their relative locations can be determined from the plot.

You can use the **Data Cursor** tool from the **Tools** menu in the figure window to identify the items in this plot. By clicking a stock (vector), you can read off that stock's loadings for each factor. By clicking an observation (point), you can read off that observation's scores for each factor.

Partial Least Squares Regression and Principal Components Regression

This example shows how to apply Partial Least Squares Regression (PLSR) and Principal Components Regression (PCR), and discusses the effectiveness of the two methods. PLSR and PCR are both methods to model a response variable when there are a large number of predictor variables, and those predictors are highly correlated or even collinear. Both methods construct new predictor variables, known as components, as linear combinations of the original predictor variables, but they construct those components in different ways. PCR creates components to explain the observed variability in the predictor variables, without considering the response variable at all. On the other hand, PLSR does take the response variable into account, and therefore often leads to models that are able to fit the response variable with fewer components. Whether or not that ultimately translates into a more parsimonious model, in terms of its practical use, depends on the context.

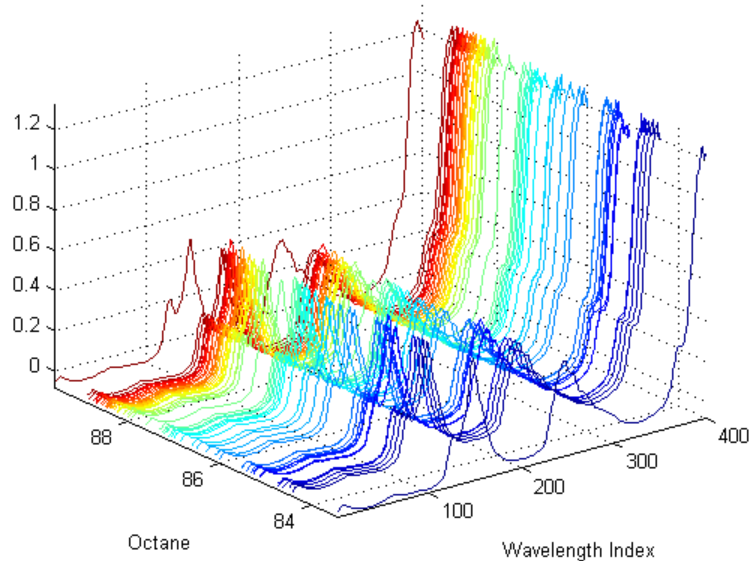
Loading the Data

Load a data set comprising spectral intensities of 60 samples of gasoline at 401 wavelengths, and their octane ratings. These data are described in Kalivas, John H., "Two Data Sets of Near Infrared Spectra," *Chemometrics and Intelligent Laboratory Systems*, v.37 (1997) pp.255-259.

```
load spectra
whos NIR octane
```

Name	Size	Bytes	Class	Attributes
NIR	60x401	192480	double	
octane	60x1	480	double	

```
[dummy,h] = sort(octane);
oldorder = get(gcf,'DefaultAxesColorOrder');
set(gcf,'DefaultAxesColorOrder',jet(60));
plot3(repmat(1:401,60,1)',repmat(octane(h),1,401)',NIR(h,:));
set(gcf,'DefaultAxesColorOrder',oldorder);
xlabel('Wavelength Index'); ylabel('Octane'); axis('tight');
grid on
```



Fitting the Data with Two Components

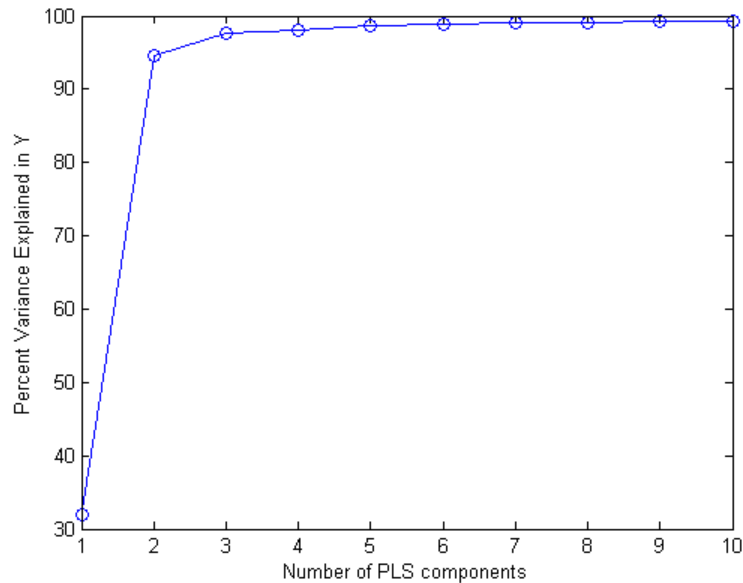
Use the `plsregress` function to fit a PLSR model with ten PLS components and one response.

```
X = NIR;
y = octane;
[n,p] = size(X);
[Xloadings,Yloadings,Xscores,Yscores,betaPLS10,PLSPctVar] = plsregress(...
    X,y,10);
```

Ten components may be more than will be needed to adequately fit the data, but diagnostics from this fit can be used to make a choice of a simpler model with fewer components. For example, one quick way to choose the number of components is to plot the percent of variance explained in the response variable as a function of the number of components.

```
plot(1:10,cumsum(100*PLSPctVar(2,:)),'-bo');
xlabel('Number of PLS components');
```

```
ylabel('Percent Variance Explained in Y');
```



In practice, more care would probably be advisable in choosing the number of components. Cross-validation, for instance, is a widely-used method that will be illustrated later in this example. For now, the above plot suggests that PLSR with two components explains most of the variance in the observed y . Compute the fitted response values for the two-component model.

```
[Xloadings,Yloadings,Xscores,Yscores,betaPLS] = plsregress(X,y,2);
yfitPLS = [ones(n,1) X]*betaPLS;
```

Next, fit a PCR model with two principal components. The first step is to perform Principal Components Analysis on X , using the `pca` function, and retaining two principal components. PCR is then just a linear regression of the response variable on those two components. It often makes sense to normalize each variable first by its standard deviation when the variables have very different amounts of variability, however, that is not done here.

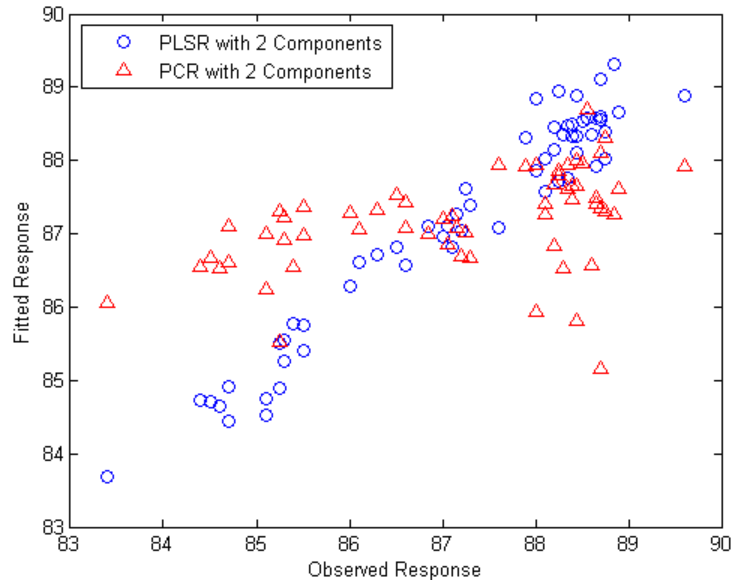
```
[PCALoadings,PCAScores,PCAVar] = pca(X,'Economy',false);
betaPCR = regress(y-mean(y), PCAScores(:,1:2));
```

To make the PCR results easier to interpret in terms of the original spectral data, transform to regression coefficients for the original, uncentered variables.

```
betaPCR = PCALoadings(:,1:2)*betaPCR;
betaPCR = [mean(y) - mean(X)*betaPCR; betaPCR];
yfitPCR = [ones(n,1) X]*betaPCR;
```

Plot fitted vs. observed response for the PLSR and PCR fits.

```
plot(y,yfitPLS,'bo',y,yfitPCR,'r^');
xlabel('Observed Response');
ylabel('Fitted Response');
legend({'PLSR with 2 Components' 'PCR with 2 Components'}, ...
       'location','NW');
```



In a sense, the comparison in the plot above is not a fair one -- the number of components (two) was chosen by looking at how well a two-component PLSR

model predicted the response, and there's no reason why the PCR model should be restricted to that same number of components. With the same number of components, however, PLSR does a much better job at fitting y . In fact, looking at the horizontal scatter of fitted values in the plot above, PCR with two components is hardly better than using a constant model. The r -squared values from the two regressions confirm that.

```
TSS = sum((y-mean(y)).^2);  
RSS_PLS = sum((y-yfitPLS).^2);  
rsquaredPLS = 1 - RSS_PLS/TSS
```

```
rsquaredPLS =
```

```
    0.9466
```

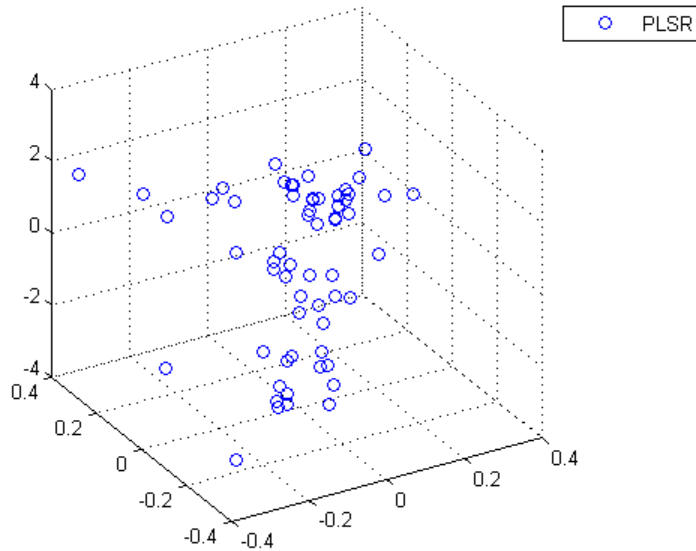
```
RSS_PCR = sum((y-yfitPCR).^2);  
rsquaredPCR = 1 - RSS_PCR/TSS
```

```
rsquaredPCR =
```

```
    0.1962
```

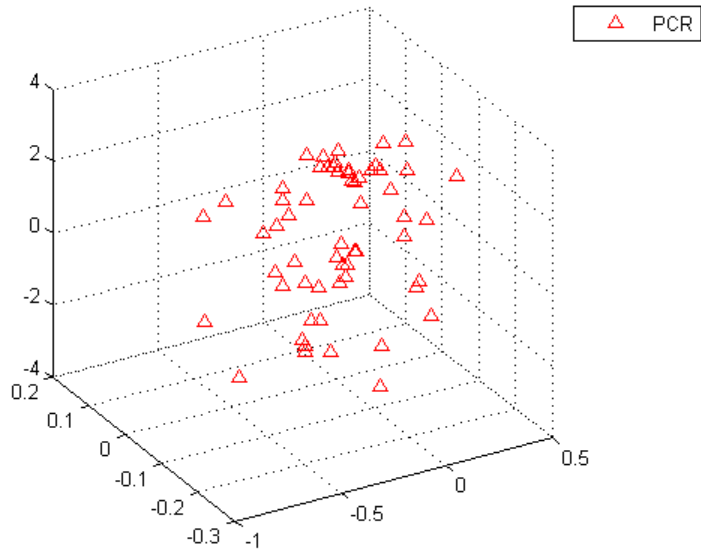
Another way to compare the predictive power of the two models is to plot the response variable against the two predictors in both cases.

```
plot3(Xscores(:,1),Xscores(:,2),y-mean(y),'bo');  
legend('PLSR');  
grid on; view(-30,30);
```



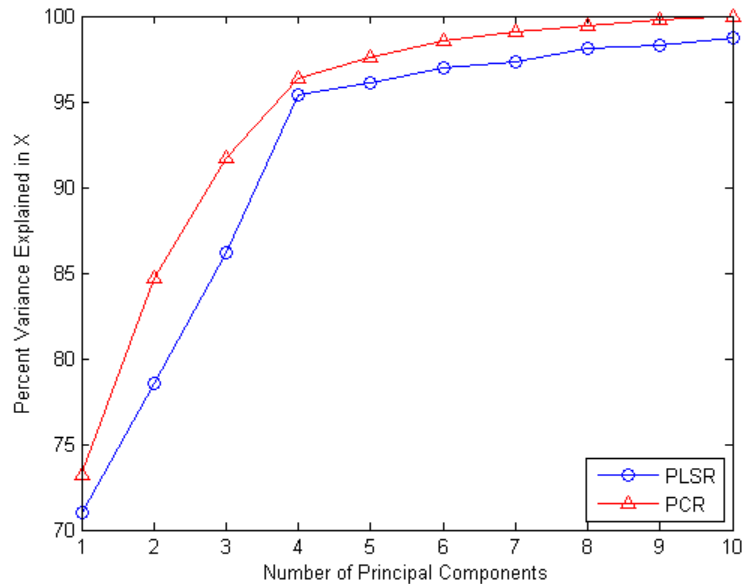
It's a little hard to see without being able to interactively rotate the figure, but the PLSR plot above shows points closely scattered about a plane. On the other hand, the PCR plot below shows a cloud of points with little indication of a linear relationship.

```
plot3(PCAScores(:,1),PCAScores(:,2),y-mean(y),'r^');  
legend('PCR');  
grid on; view(-30,30);
```

Notice that while the two PLS components are much better predictors of the observed y , the following figure shows that they explain somewhat less variance in the observed X than the first two principal components used in the PCR.

```
plot(1:10,100*cumsum(PLSPctVar(1,:)),'b-o',1:10, ...
     100*cumsum(PCAVar(1:10))/sum(PCAVar(1:10)),'r-^');
xlabel('Number of Principal Components');
ylabel('Percent Variance Explained in X');
legend({'PLSR' 'PCR'},'location','SE');
```



The fact that the PCR curve is uniformly higher suggests why PCR with two components does such a poor job, relative to PLSR, in fitting y . PCR constructs components to best explain X , and as a result, those first two components ignore the information in the data that is important in fitting the observed y .

Fitting with More Components

As more components are added in PCR, it will necessarily do a better job of fitting the original data y , simply because at some point most of the important predictive information in X will be present in the principal components. For example, the following figure shows that the difference in residuals for the two methods is much less dramatic when using ten components than it was for two components.

```

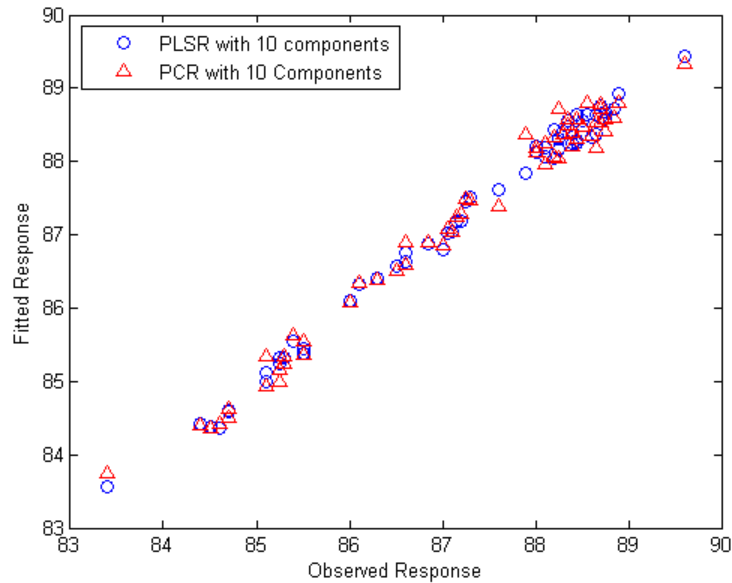
yfitPLS10 = [ones(n,1) X]*betaPLS10;
betaPCR10 = regress(y-mean(y), PCAScores(:,1:10));
betaPCR10 = PCALoadings(:,1:10)*betaPCR10;
betaPCR10 = [mean(y) - mean(X)*betaPCR10; betaPCR10];
yfitPCR10 = [ones(n,1) X]*betaPCR10;

```

```

plot(y,yfitPLS10,'bo',y,yfitPCR10,'r^');
xlabel('Observed Response');
ylabel('Fitted Response');
legend({'PLSR with 10 components' 'PCR with 10 Components'}, ...
'location','NW');

```



Both models fit y fairly accurately, although PLSR still makes a slightly more accurate fit. However, ten components is still an arbitrarily-chosen number for either model.

Choosing the Number of Components with Cross-Validation

It's often useful to choose the number of components to minimize the expected error when predicting the response from future observations on the predictor variables. Simply using a large number of components will do a good job in fitting the current observed data, but is a strategy that leads to overfitting. Fitting the current data too well results in a model that does not generalize well to other data, and gives an overly-optimistic estimate of the expected error.

Cross-validation is a more statistically sound method for choosing the number of components in either PLSR or PCR. It avoids overfitting data by not reusing the same data to both fit a model and to estimate prediction error. Thus, the estimate of prediction error is not optimistically biased downwards.

`plsregress` has an option to estimate the mean squared prediction error (MSEP) by cross-validation, in this case using 10-fold C-V.

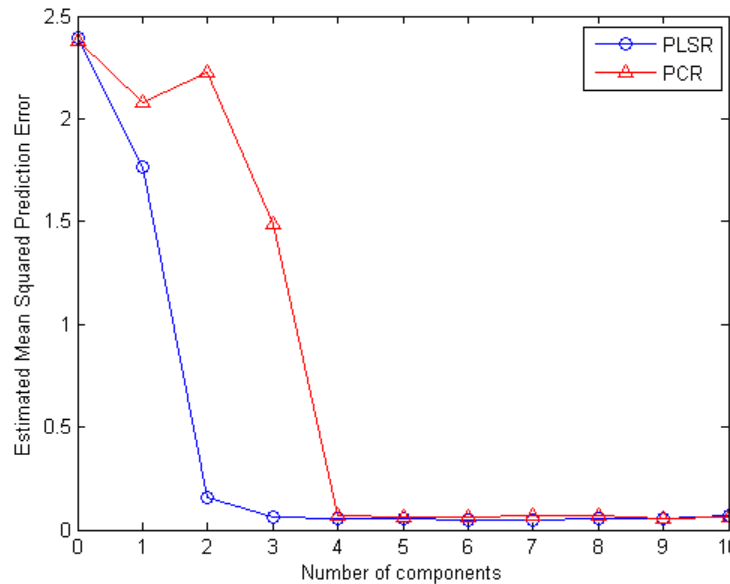
```
[X1,Y1,Xs,Ys,beta,pctVar,PLSmsep] = plsregress(X,y,10,'CV',10);
```

For PCR, `crossval` combined with a simple function to compute the sum of squared errors for PCR, can estimate the MSEP, again using 10-fold cross-validation.

```
PCRmsep = sum(crossval(@pcrsse,X,y,'Kfold',10),1) / n;
```

The MSEP curve for PLSR indicates that two or three components does about as good a job as possible. On the other hand, PCR needs four components to get the same prediction accuracy.

```
plot(0:10,PLSmsep(2,:), 'b-o',0:10,PCRmsep, 'r-^');  
xlabel('Number of components');  
ylabel('Estimated Mean Squared Prediction Error');  
legend({'PLSR' 'PCR'}, 'location', 'NE');
```



In fact, the second component in PCR *increases* the prediction error of the model, suggesting that the combination of predictor variables contained in that component is not strongly correlated with y . Again, that's because PCR constructs components to explain variation in X , not y .

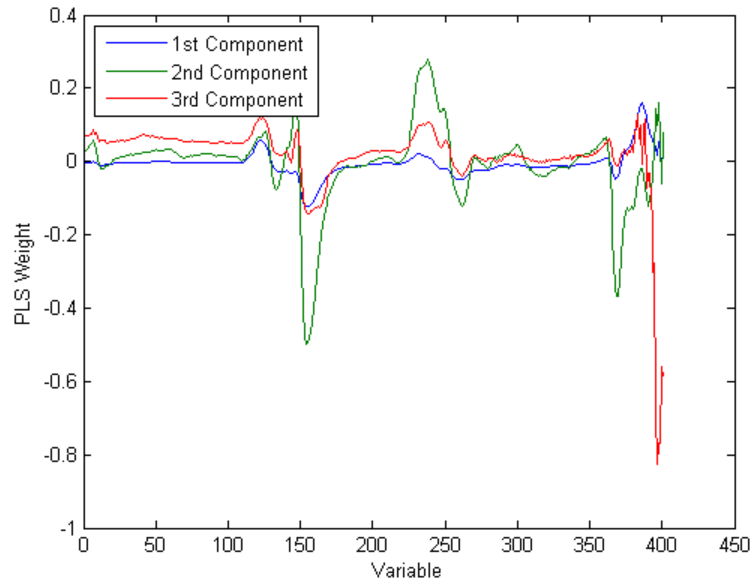
Model Parsimony

So if PCR requires four components to get the same prediction accuracy as PLSR with three components, is the PLSR model more parsimonious? That depends on what aspect of the model you consider.

The PLS weights are the linear combinations of the original variables that define the PLS components, i.e., they describe how strongly each component in the PLSR depends on the original variables, and in what direction.

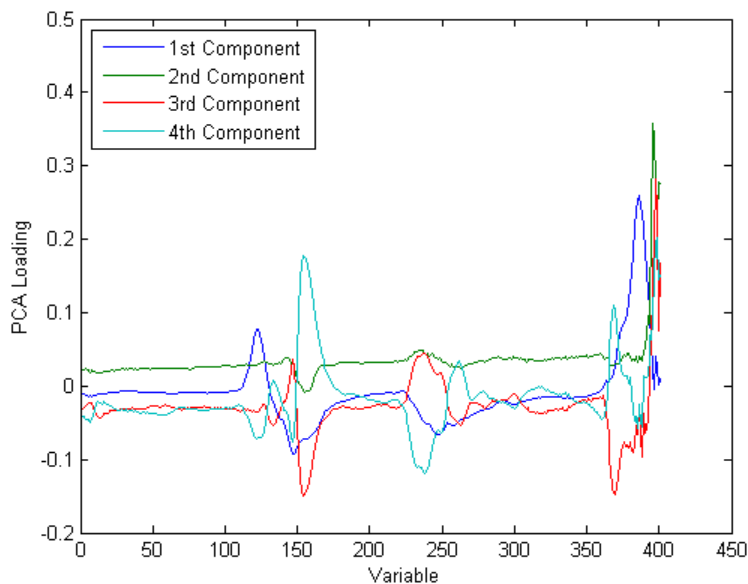
```
[X1,Y1,Xs,Ys,beta,pctVar,mse,stats] = plsregress(X,y,3);
plot(1:401,stats.W,'-');
xlabel('Variable');
ylabel('PLS Weight');
```

```
legend({'1st Component' '2nd Component' '3rd Component'}, ...
      'location','NW');
```



Similarly, the PCA loadings describe how strongly each component in the PCR depends on the original variables.

```
plot(1:401,PCALoadings(:,1:4),'-');
xlabel('Variable');
ylabel('PCA Loading');
legend({'1st Component' '2nd Component' '3rd Component' ...
      '4th Component'},'location','NW');
```



For either PLSR or PCR, it may be that each component can be given a physically meaningful interpretation by inspecting which variables it weights most heavily. For instance, with these spectral data it may be possible to interpret intensity peaks in terms of compounds present in the gasoline, and then to observe that weights for a particular component pick out a small number of those compounds. From that perspective, fewer components are simpler to interpret, and because PLSR often requires fewer components to predict the response adequately, it leads to more parsimonious models.

On the other hand, both PLSR and PCR result in one regression coefficient for each of the original predictor variables, plus an intercept. In that sense, neither is more parsimonious, because regardless of how many components are used, both models depend on all predictors. More concretely, for these data, both models need 401 spectral intensity values in order to make a prediction.

However, the ultimate goal may be to reduce the original set of variables to a smaller subset still able to predict the response accurately. For example, it may be possible to use the PLS weights or the PCA loadings to select only

those variables that contribute most to each component. As shown earlier, some components from a PCR model fit may serve primarily to describe the variation in the predictor variables, and may include large weights for variables that are not strongly correlated with the response. Thus, PCR can lead to retaining variables that are unnecessary for prediction.

For the data used in this example, the difference in the number of components needed by PLSR and PCR for accurate prediction is not great, and the PLS weights and PCA loadings seem to pick out the same variables. That may not be true for other data.

Cluster Analysis

- “Introduction to Cluster Analysis” on page 11-2
- “Hierarchical Clustering” on page 11-3
- “k-Means Clustering” on page 11-21
- “Gaussian Mixture Models” on page 11-28

Introduction to Cluster Analysis

Cluster analysis, also called *segmentation analysis* or *taxonomy analysis*, creates groups, or *clusters*, of data. Clusters are formed in such a way that objects in the same cluster are very similar and objects in different clusters are very distinct. Measures of similarity depend on the application.

“Hierarchical Clustering” on page 11-3 groups data over a variety of scales by creating a cluster tree or *dendrogram*. The tree is not a single set of clusters, but rather a multilevel hierarchy, where clusters at one level are joined as clusters at the next level. This allows you to decide the level or scale of clustering that is most appropriate for your application. The Statistics Toolbox function `clusterdata` performs all of the necessary steps for you. It incorporates the `pdist`, `linkage`, and `cluster` functions, which may be used separately for more detailed analysis. The `dendrogram` function plots the cluster tree.

“k-Means Clustering” on page 11-21 is a partitioning method. The function `kmeans` partitions data into k mutually exclusive clusters, and returns the index of the cluster to which it has assigned each observation. Unlike hierarchical clustering, k-means clustering operates on actual observations (rather than the larger set of dissimilarity measures), and creates a single level of clusters. The distinctions mean that k-means clustering is often more suitable than hierarchical clustering for large amounts of data.

“Gaussian Mixture Models” on page 11-28 form clusters by representing the probability density function of observed variables as a mixture of multivariate normal densities. Mixture models of the `gmdistribution` class use an expectation maximization (EM) algorithm to fit data, which assigns posterior probabilities to each component density with respect to each observation. Clusters are assigned by selecting the component that maximizes the posterior probability. Clustering using Gaussian mixture models is sometimes considered a soft clustering method. The posterior probabilities for each point indicate that each data point has some probability of belonging to each cluster. Like k-means clustering, Gaussian mixture modeling uses an iterative algorithm that converges to a local optimum. Gaussian mixture modeling may be more appropriate than k-means clustering when clusters have different sizes and correlation within them.

Hierarchical Clustering

In this section...

“Introduction to Hierarchical Clustering” on page 11-3

“Algorithm Description” on page 11-3

“Similarity Measures” on page 11-4

“Linkages” on page 11-6

“Dendrograms” on page 11-8

“Verify the Cluster Tree” on page 11-10

“Create Clusters” on page 11-16

Introduction to Hierarchical Clustering

Hierarchical clustering groups data over a variety of scales by creating a cluster tree or *dendrogram*. The tree is not a single set of clusters, but rather a multilevel hierarchy, where clusters at one level are joined as clusters at the next level. This allows you to decide the level or scale of clustering that is most appropriate for your application. The Statistics Toolbox function `clusterdata` supports agglomerative clustering and performs all of the necessary steps for you. It incorporates the `pdist`, `linkage`, and `cluster` functions, which you can use separately for more detailed analysis. The `dendrogram` function plots the cluster tree.

Algorithm Description

To perform agglomerative hierarchical cluster analysis on a data set using Statistics Toolbox functions, follow this procedure:

- 1 Find the similarity or dissimilarity between every pair of objects in the data set.** In this step, you calculate the *distance* between objects using the `pdist` function. The `pdist` function supports many different ways to compute this measurement. See “Similarity Measures” on page 11-4 for more information.
- 2 Group the objects into a binary, hierarchical cluster tree.** In this step, you link pairs of objects that are in close proximity using the `linkage`

function. The `linkage` function uses the distance information generated in step 1 to determine the proximity of objects to each other. As objects are paired into binary clusters, the newly formed clusters are grouped into larger clusters until a hierarchical tree is formed. See “Linkages” on page 11-6 for more information.

3 Determine where to cut the hierarchical tree into clusters. In this step, you use the `cluster` function to prune branches off the bottom of the hierarchical tree, and assign all the objects below each cut to a single cluster. This creates a partition of the data. The `cluster` function can create these clusters by detecting natural groupings in the hierarchical tree or by cutting off the hierarchical tree at an arbitrary point.

The following sections provide more information about each of these steps.

Note The Statistics Toolbox function `clusterdata` performs all of the necessary steps for you. You do not need to execute the `pdist`, `linkage`, or `cluster` functions separately.

Similarity Measures

You use the `pdist` function to calculate the distance between every pair of objects in a data set. For a data set made up of m objects, there are $m*(m - 1)/2$ pairs in the data set. The result of this computation is commonly known as a distance or dissimilarity matrix.

There are many ways to calculate this distance information. By default, the `pdist` function calculates the Euclidean distance between objects; however, you can specify one of several other options. See `pdist` for more information.

Note You can optionally normalize the values in the data set before calculating the distance information. In a real world data set, variables can be measured against different scales. For example, one variable can measure Intelligence Quotient (IQ) test scores and another variable can measure head circumference. These discrepancies can distort the proximity calculations. Using the `zscore` function, you can convert all the values in the data set to use the same proportional scale. See `zscore` for more information.

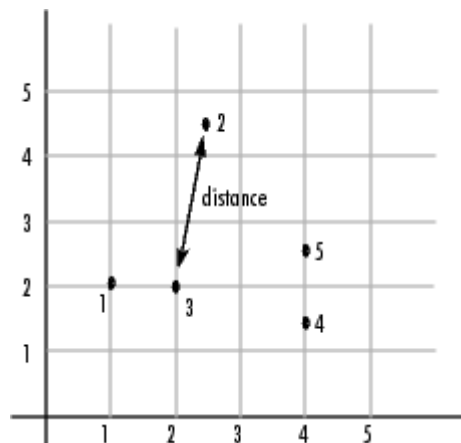
For example, consider a data set, X , made up of five objects where each object is a set of x,y coordinates.

- **Object 1:** 1, 2
- **Object 2:** 2.5, 4.5
- **Object 3:** 2, 2
- **Object 4:** 4, 1.5
- **Object 5:** 4, 2.5

You can define this data set as a matrix

```
X = [1 2;2.5 4.5;2 2;4 1.5;4 2.5]
```

and pass it to `pdist`. The `pdist` function calculates the distance between object 1 and object 2, object 1 and object 3, and so on until the distances between all the pairs have been calculated. The following figure plots these objects in a graph. The Euclidean distance between object 2 and object 3 is shown to illustrate one interpretation of distance.



Distance Information

The `pdist` function returns this distance information in a vector, Y , where each element contains the distance between a pair of objects.

```

Y = pdist(X)
Y =
  Columns 1 through 5
    2.9155    1.0000    3.0414    3.0414    2.5495
  Columns 6 through 10
    3.3541    2.5000    2.0616    2.0616    1.0000

```

To make it easier to see the relationship between the distance information generated by `pdist` and the objects in the original data set, you can reformat the distance vector into a matrix using the `squareform` function. In this matrix, element i,j corresponds to the distance between object i and object j in the original data set. In the following example, element 1,1 represents the distance between object 1 and itself (which is zero). Element 1,2 represents the distance between object 1 and object 2, and so on.

```

squareform(Y)
ans =
    0    2.9155    1.0000    3.0414    3.0414
  2.9155    0    2.5495    3.3541    2.5000
  1.0000    2.5495    0    2.0616    2.0616
  3.0414    3.3541    2.0616    0    1.0000
  3.0414    2.5000    2.0616    1.0000    0

```

Linkages

Once the proximity between objects in the data set has been computed, you can determine how objects in the data set should be grouped into clusters, using the `linkage` function. The `linkage` function takes the distance information generated by `pdist` and links pairs of objects that are close together into binary clusters (clusters made up of two objects). The `linkage` function then links these newly formed clusters to each other and to other objects to create bigger clusters until all the objects in the original data set are linked together in a hierarchical tree.

For example, given the distance vector `Y` generated by `pdist` from the sample data set of x - and y -coordinates, the `linkage` function generates a hierarchical cluster tree, returning the linkage information in a matrix, `Z`.

```

Z = linkage(Y)
Z =
    4.0000    5.0000    1.0000

```

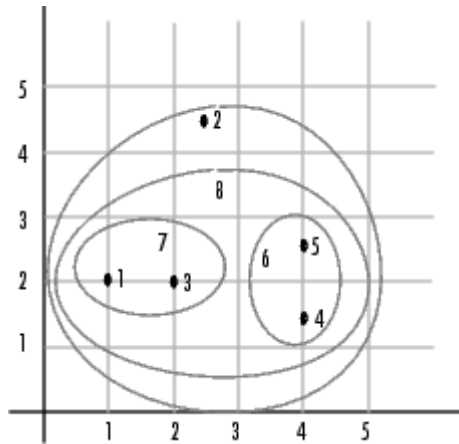
1.0000	3.0000	1.0000
6.0000	7.0000	2.0616
2.0000	8.0000	2.5000

In this output, each row identifies a link between objects or clusters. The first two columns identify the objects that have been linked. The third column contains the distance between these objects. For the sample data set of x - and y -coordinates, the `linkage` function begins by grouping objects 4 and 5, which have the closest proximity (distance value = 1.0000). The `linkage` function continues by grouping objects 1 and 3, which also have a distance value of 1.0000.

The third row indicates that the `linkage` function grouped objects 6 and 7. If the original sample data set contained only five objects, what are objects 6 and 7? Object 6 is the newly formed binary cluster created by the grouping of objects 4 and 5. When the `linkage` function groups two objects into a new cluster, it must assign the cluster a unique index value, starting with the value $m+1$, where m is the number of objects in the original data set. (Values 1 through m are already used by the original data set.) Similarly, object 7 is the cluster formed by grouping objects 1 and 3.

`linkage` uses distances to determine the order in which it clusters objects. The distance vector Υ contains the distances between the original objects 1 through 5. But `linkage` must also be able to determine distances involving clusters that it creates, such as objects 6 and 7. By default, `linkage` uses a method known as single linkage. However, there are a number of different methods available. See the `linkage` reference page for more information.

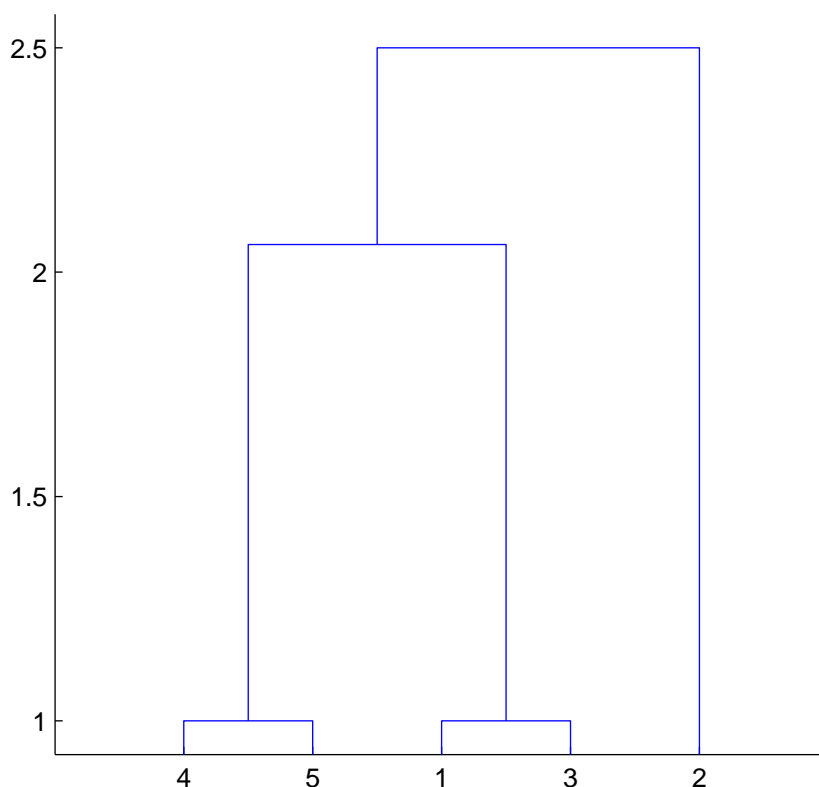
As the final cluster, the `linkage` function grouped object 8, the newly formed cluster made up of objects 6 and 7, with object 2 from the original data set. The following figure graphically illustrates the way `linkage` groups the objects into a hierarchy of clusters.



Dendrograms

The hierarchical, binary cluster tree created by the linkage function is most easily understood when viewed graphically. The Statistics Toolbox function `dendrogram` plots the tree, as follows:

```
dendrogram(Z)
```

In the figure, the numbers along the horizontal axis represent the indices of the objects in the original data set. The links between objects are represented as upside-down U-shaped lines. The height of the U indicates the distance between the objects. For example, the link representing the cluster containing objects 1 and 3 has a height of 1. The link representing the cluster that groups object 2 together with objects 1, 3, 4, and 5, (which are already clustered as object 8) has a height of 2.5. The height represents the distance linkage computes between objects 2 and 8. For more information about creating a dendrogram diagram, see the [dendrogram](#) reference page.

Verify the Cluster Tree

After linking the objects in a data set into a hierarchical cluster tree, you might want to verify that the distances (that is, heights) in the tree reflect the original distances accurately. In addition, you might want to investigate natural divisions that exist among links between objects. Statistics Toolbox functions are available for both of these tasks, as described in the following sections:

- “Verify Dissimilarity” on page 11-10
- “Verify Consistency” on page 11-11

Verify Dissimilarity

In a hierarchical cluster tree, any two objects in the original data set are eventually linked together at some level. The height of the link represents the distance between the two clusters that contain those two objects. This height is known as the *cophenetic distance* between the two objects. One way to measure how well the cluster tree generated by the `linkage` function reflects your data is to compare the cophenetic distances with the original distance data generated by the `pdist` function. If the clustering is valid, the linking of objects in the cluster tree should have a strong correlation with the distances between objects in the distance vector. The `cophenet` function compares these two sets of values and computes their correlation, returning a value called the *cophenetic correlation coefficient*. The closer the value of the cophenetic correlation coefficient is to 1, the more accurately the clustering solution reflects your data.

You can use the cophenetic correlation coefficient to compare the results of clustering the same data set using different distance calculation methods or clustering algorithms. For example, you can use the `cophenet` function to evaluate the clusters created for the sample data set

```
c = cophenet(Z,Y)
c =
    0.8615
```

where `Z` is the matrix output by the `linkage` function and `Y` is the distance vector output by the `pdist` function.

Execute `pdist` again on the same data set, this time specifying the city block metric. After running the `linkage` function on this new `pdist` output using the average linkage method, call `cophenet` to evaluate the clustering solution.

```
Y = pdist(X, 'cityblock');
Z = linkage(Y, 'average');
c = cophenet(Z,Y)
c =
    0.9047
```

The cophenetic correlation coefficient shows that using a different distance and linkage method creates a tree that represents the original distances slightly better.

Verify Consistency

One way to determine the natural cluster divisions in a data set is to compare the height of each link in a cluster tree with the heights of neighboring links below it in the tree.

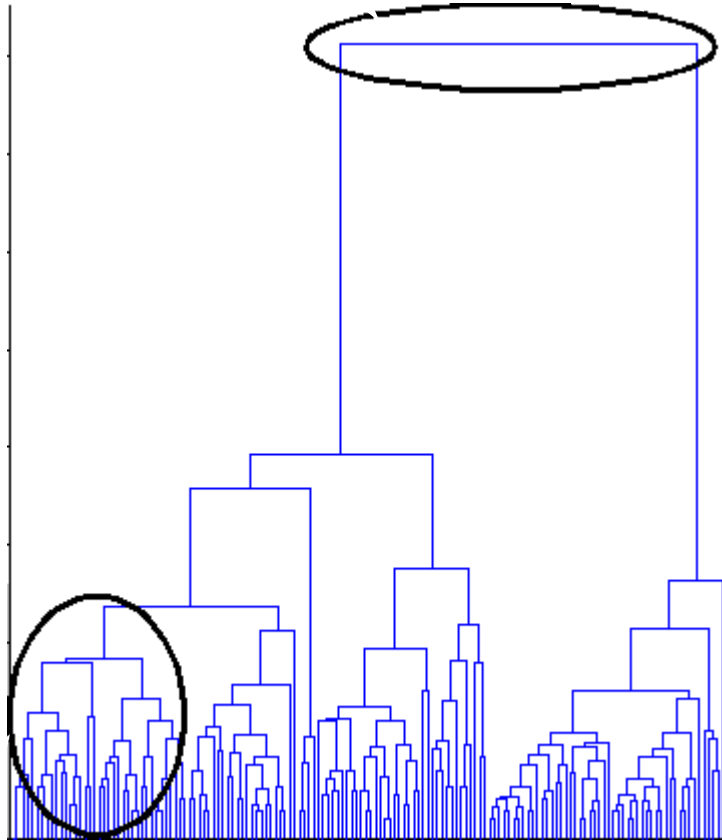
A link that is approximately the same height as the links below it indicates that there are no distinct divisions between the objects joined at this level of the hierarchy. These links are said to exhibit a high level of consistency, because the distance between the objects being joined is approximately the same as the distances between the objects they contain.

On the other hand, a link whose height differs noticeably from the height of the links below it indicates that the objects joined at this level in the cluster tree are much farther apart from each other than their components were when they were joined. This link is said to be inconsistent with the links below it.

In cluster analysis, inconsistent links can indicate the border of a natural division in a data set. The `cluster` function uses a quantitative measure of inconsistency to determine where to partition your data set into clusters.

The following dendrogram illustrates inconsistent links. Note how the objects in the dendrogram fall into two groups that are connected by links at a much higher level in the tree. These links are inconsistent when compared with the links below them in the hierarchy.

These links show inconsistency when compared to the links below them.



These links show consistency.

The relative consistency of each link in a hierarchical cluster tree can be quantified and expressed as the *inconsistency coefficient*. This value compares the height of a link in a cluster hierarchy with the average height of links below it. Links that join distinct clusters have a high inconsistency coefficient; links that join indistinct clusters have a low inconsistency coefficient.

To generate a listing of the inconsistency coefficient for each link in the cluster tree, use the `inconsistent` function. By default, the `inconsistent`

function compares each link in the cluster hierarchy with adjacent links that are less than two levels below it in the cluster hierarchy. This is called the *depth* of the comparison. You can also specify other depths. The objects at the bottom of the cluster tree, called leaf nodes, that have no further objects below them, have an inconsistency coefficient of zero. Clusters that join two leaves also have a zero inconsistency coefficient.

For example, you can use the `inconsistent` function to calculate the inconsistency values for the links created by the `linkage` function in “Linkages” on page 11-6.

```
I = inconsistent(Z)
I =
    1.0000         0    1.0000         0
    1.0000         0    1.0000         0
    1.3539    0.6129    3.0000    1.1547
    2.2808    0.3100    2.0000    0.7071
```

The `inconsistent` function returns data about the links in an $(m-1)$ -by-4 matrix, whose columns are described in the following table.

Column	Description
1	Mean of the heights of all the links included in the calculation
2	Standard deviation of all the links included in the calculation
3	Number of links included in the calculation
4	Inconsistency coefficient

In the sample output, the first row represents the link between objects 4 and 5. This cluster is assigned the index 6 by the `linkage` function. Because both 4 and 5 are leaf nodes, the inconsistency coefficient for the cluster is zero. The second row represents the link between objects 1 and 3, both of which are also leaf nodes. This cluster is assigned the index 7 by the `linkage` function.

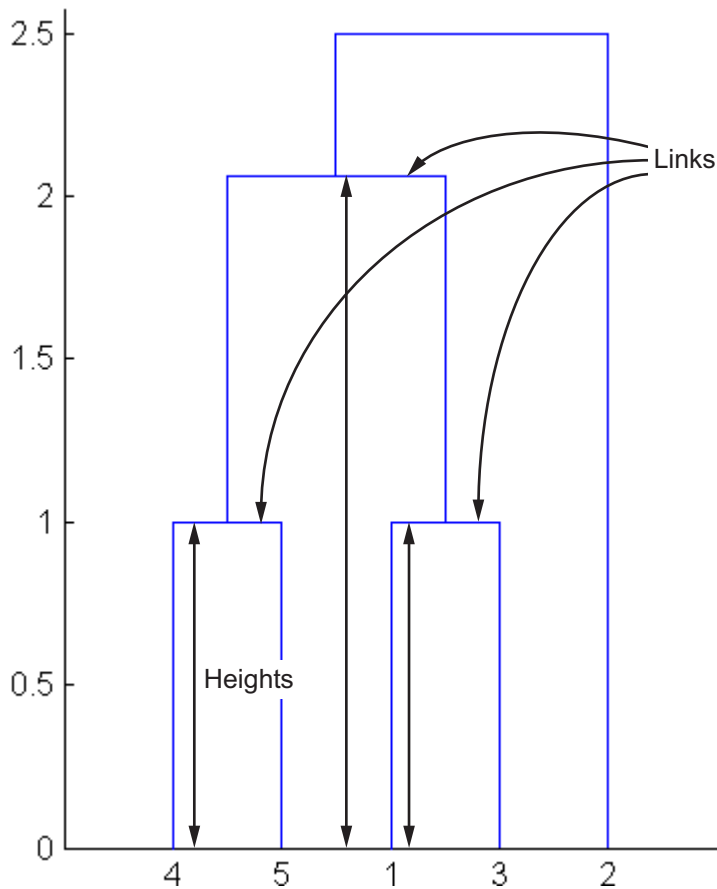
The third row evaluates the link that connects these two clusters, objects 6 and 7. (This new cluster is assigned index 8 in the `linkage` output). Column 3 indicates that three links are considered in the calculation: the link itself and the two links directly below it in the hierarchy. Column 1 represents the mean of the heights of these links. The `inconsistent` function uses the height

information output by the linkage function to calculate the mean. Column 2 represents the standard deviation between the links. The last column contains the inconsistency value for these links, 1.1547. It is the difference between the current link height and the mean, normalized by the standard deviation:

$$(2.0616 - 1.3539) / .6129$$

ans =
1.1547

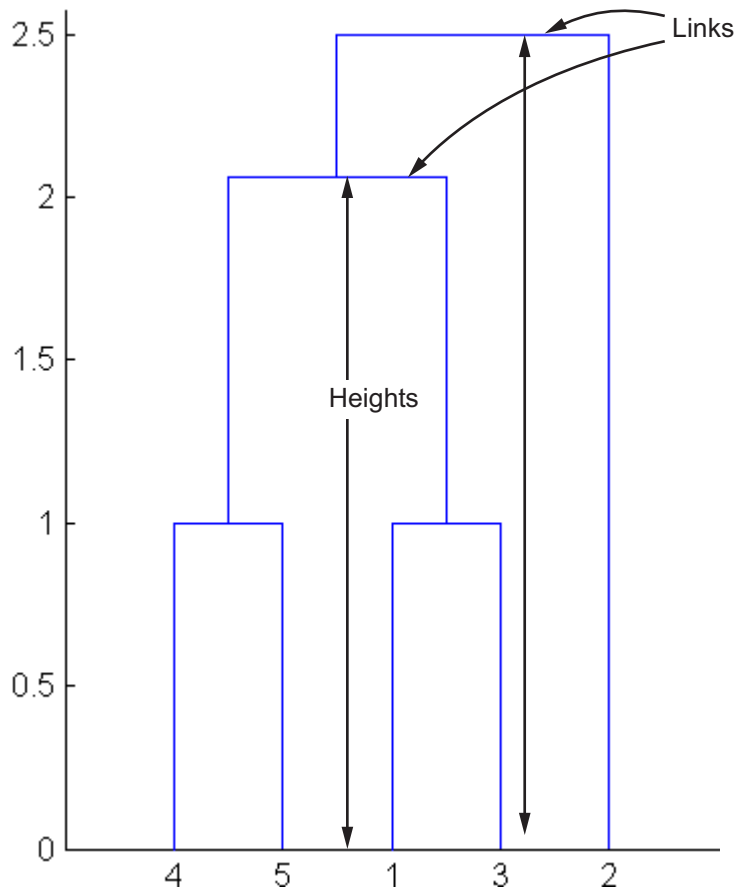
The following figure illustrates the links and heights included in this calculation.



Note In the preceding figure, the lower limit on the y -axis is set to 0 to show the heights of the links. To set the lower limit to 0, select **Axes Properties** from the **Edit** menu, click the **Y Axis** tab, and enter 0 in the field immediately to the right of **Y Limits**.

Row 4 in the output matrix describes the link between object 8 and object 2. Column 3 indicates that two links are included in this calculation: the link itself and the link directly below it in the hierarchy. The inconsistency coefficient for this link is 0.7071.

The following figure illustrates the links and heights included in this calculation.



Create Clusters

After you create the hierarchical tree of binary clusters, you can prune the tree to partition your data into clusters using the `cluster` function. The `cluster` function lets you create clusters in two ways, as discussed in the following sections:

- “Find Natural Divisions in Data” on page 11-17
- “Specify Arbitrary Clusters” on page 11-18

Find Natural Divisions in Data

The hierarchical cluster tree may naturally divide the data into distinct, well-separated clusters. This can be particularly evident in a dendrogram diagram created from data where groups of objects are densely packed in certain areas and not in others. The inconsistency coefficient of the links in the cluster tree can identify these divisions where the similarities between objects change abruptly. (See “Verify the Cluster Tree” on page 11-10 for more information about the inconsistency coefficient.) You can use this value to determine where the `cluster` function creates cluster boundaries.

For example, if you use the `cluster` function to group the sample data set into clusters, specifying an inconsistency coefficient threshold of 1.2 as the value of the `cutoff` argument, the `cluster` function groups all the objects in the sample data set into one cluster. In this case, none of the links in the cluster hierarchy had an inconsistency coefficient greater than 1.2.

```
T = cluster(Z, 'cutoff', 1.2)
T =
     1
     1
     1
     1
     1
```

The `cluster` function outputs a vector, `T`, that is the same size as the original data set. Each element in this vector contains the number of the cluster into which the corresponding object from the original data set was placed.

If you lower the inconsistency coefficient threshold to 0.8, the `cluster` function divides the sample data set into three separate clusters.

```
T = cluster(Z, 'cutoff', 0.8)
T =
     3
     2
     3
     1
     1
```

This output indicates that objects 1 and 3 were placed in cluster 1, objects 4 and 5 were placed in cluster 2, and object 2 was placed in cluster 3.

When clusters are formed in this way, the cutoff value is applied to the inconsistency coefficient. These clusters may, but do not necessarily, correspond to a horizontal slice across the dendrogram at a certain height. If you want clusters corresponding to a horizontal slice of the dendrogram, you can either use the `criterion` option to specify that the cutoff should be based on distance rather than inconsistency, or you can specify the number of clusters directly as described in the following section.

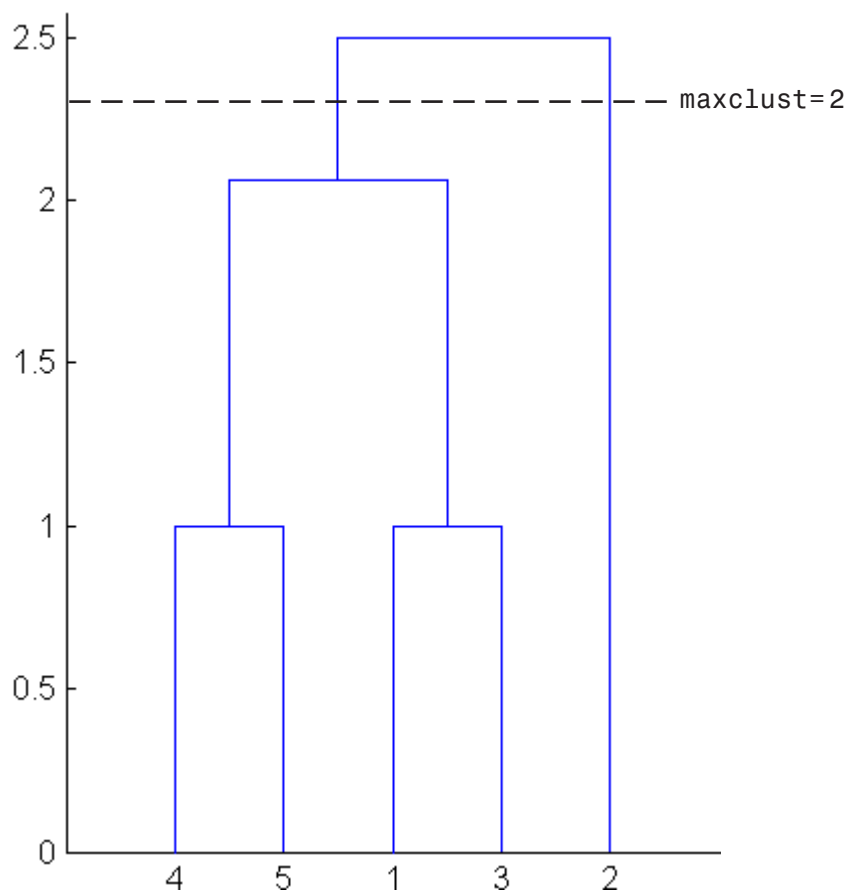
Specify Arbitrary Clusters

Instead of letting the `cluster` function create clusters determined by the natural divisions in the data set, you can specify the number of clusters you want created.

For example, you can specify that you want the `cluster` function to partition the sample data set into two clusters. In this case, the `cluster` function creates one cluster containing objects 1, 3, 4, and 5 and another cluster containing object 2.

```
T = cluster(Z, 'maxclust', 2)
T =
     2
     1
     2
     2
     2
```

To help you visualize how the `cluster` function determines these clusters, the following figure shows the dendrogram of the hierarchical cluster tree. The horizontal dashed line intersects two lines of the dendrogram, corresponding to setting `'maxclust'` to 2. These two lines partition the objects into two clusters: the objects below the left-hand line, namely 1, 3, 4, and 5, belong to one cluster, while the object below the right-hand line, namely 2, belongs to the other cluster.



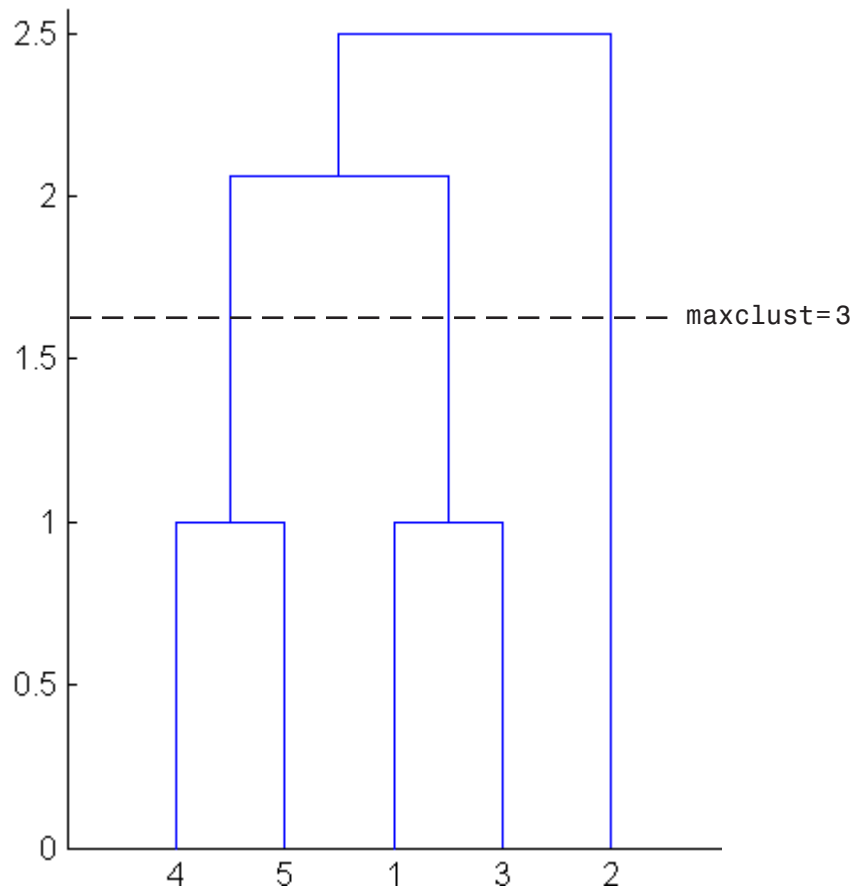
On the other hand, if you set 'maxclust' to 3, the cluster function groups objects 4 and 5 in one cluster, objects 1 and 3 in a second cluster, and object 2 in a third cluster. The following command illustrates this.

```
T = cluster(Z, 'maxclust', 3)
```

```
T =
```

```
 1  
 3  
 1  
 2  
 2
```

This time, the `cluster` function cuts off the hierarchy at a lower point, corresponding to the horizontal line that intersects three lines of the dendrogram in the following figure.



k-Means Clustering

In this section...

“Introduction to k-Means Clustering” on page 11-21

“Create Clusters and Determine Separation” on page 11-22

“Determine the Correct Number of Clusters” on page 11-23

“Avoid Local Minima” on page 11-26

Introduction to k-Means Clustering

k-means clustering is a partitioning method. The function `kmeans` partitions data into k mutually exclusive clusters, and returns the index of the cluster to which it has assigned each observation. Unlike hierarchical clustering, k-means clustering operates on actual observations (rather than the larger set of dissimilarity measures), and creates a single level of clusters. The distinctions mean that k-means clustering is often more suitable than hierarchical clustering for large amounts of data.

`kmeans` treats each observation in your data as an object having a location in space. It finds a partition in which objects within each cluster are as close to each other as possible, and as far from objects in other clusters as possible. You can choose from five different distance measures, depending on the kind of data you are clustering.

Each cluster in the partition is defined by its member objects and by its centroid, or center. The centroid for each cluster is the point to which the sum of distances from all objects in that cluster is minimized. `kmeans` computes cluster centroids differently for each distance measure, to minimize the sum with respect to the measure that you specify.

`kmeans` uses an iterative algorithm that minimizes the sum of distances from each object to its cluster centroid, over all clusters. This algorithm moves objects between clusters until the sum cannot be decreased further. The result is a set of clusters that are as compact and well-separated as possible. You can control the details of the minimization using several optional input parameters to `kmeans`, including ones for the initial values of the cluster centroids, and for the maximum number of iterations.

Create Clusters and Determine Separation

The following example explores possible clustering in four-dimensional data by analyzing the results of partitioning the points into three, four, and five clusters.

Note Because each part of this example generates random numbers sequentially, i.e., without setting a new state, you must perform all steps in sequence to duplicate the results shown. If you perform the steps out of sequence, the answers will be essentially the same, but the intermediate results, number of iterations, or ordering of the silhouette plots may differ.

First, load some data:

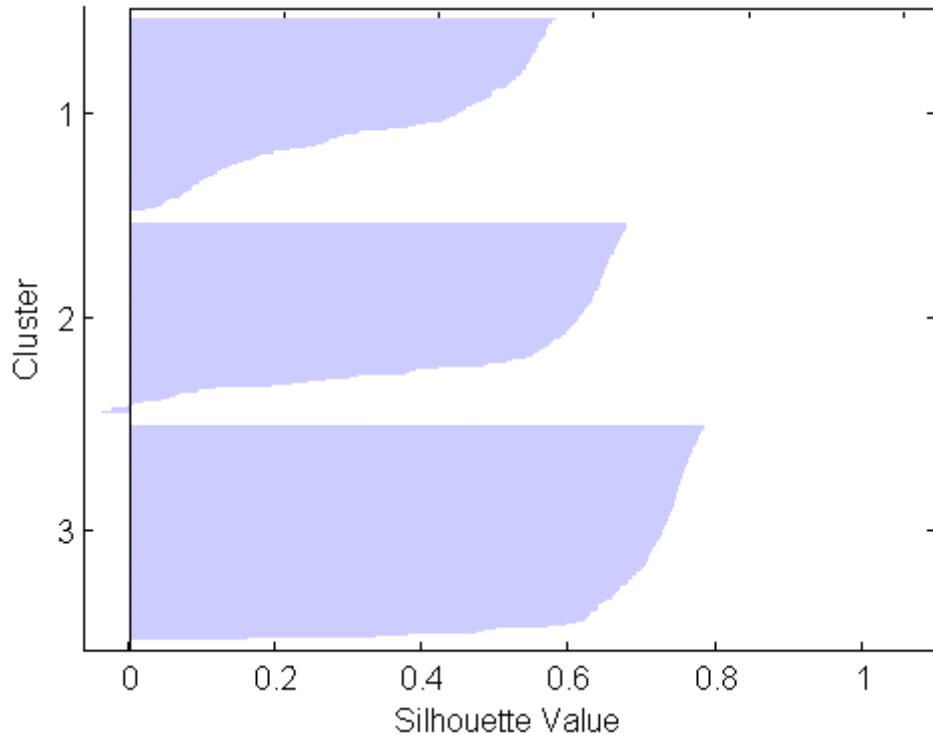
```
load kmeansdata;
size(X)
ans =
    560     4
```

Even though these data are four-dimensional, and cannot be easily visualized, `kmeans` enables you to investigate whether a group structure exists in them. Call `kmeans` with `k`, the desired number of clusters, equal to 3. For this example, specify the city block distance measure, and use the default starting method of initializing centroids from randomly selected data points:

```
idx3 = kmeans(X,3,'distance','city');
```

To get an idea of how well-separated the resulting clusters are, you can make a silhouette plot using the cluster indices output from `kmeans`. The silhouette plot displays a measure of how close each point in one cluster is to points in the neighboring clusters. This measure ranges from +1, indicating points that are very distant from neighboring clusters, through 0, indicating points that are not distinctly in one cluster or another, to -1, indicating points that are probably assigned to the wrong cluster. `silhouette` returns these values in its first output:

```
[silh3,h] = silhouette(X,idx3,'city');
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
xlabel('Silhouette Value')
ylabel('Cluster')
```



From the silhouette plot, you can see that most points in the third cluster have a large silhouette value, greater than 0.6, indicating that the cluster is somewhat separated from neighboring clusters. However, the first cluster contains many points with low silhouette values, and the second contains a few points with negative values, indicating that those two clusters are not well separated.

Determine the Correct Number of Clusters

Increase the number of clusters to see if `kmeans` can find a better grouping of the data. This time, use the optional `'display'` parameter to print information about each iteration:

```
idx4 = kmeans(X,4, 'dist','city', 'display','iter');
  iter phase      num      sum
     1     1      560    2897.56
```

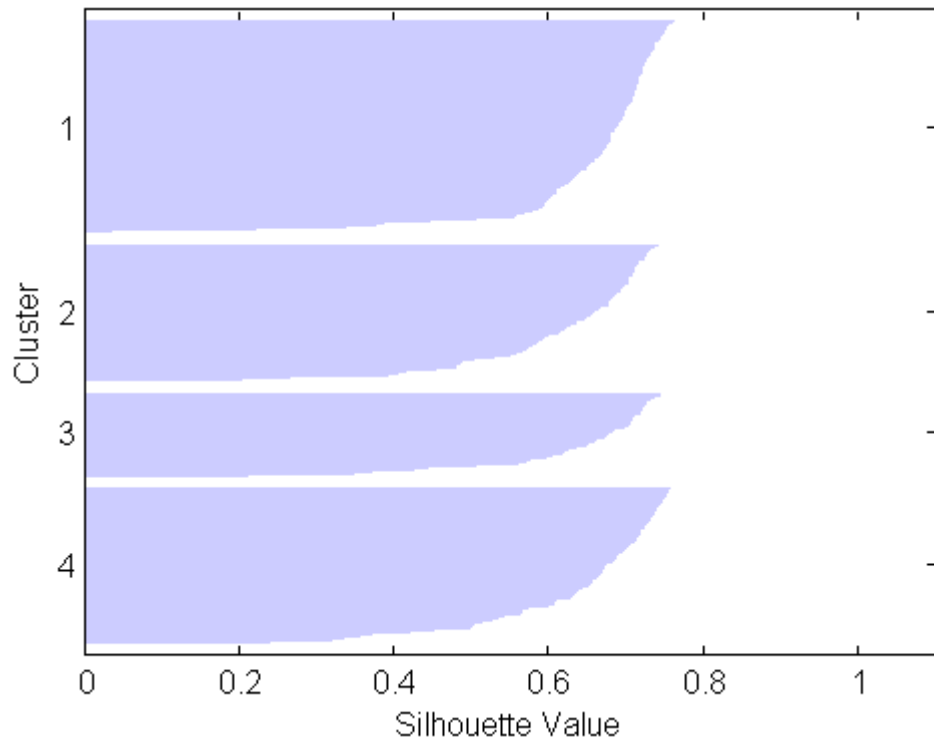
2	1	53	2736.67
3	1	50	2476.78
4	1	102	1779.68
5	1	5	1771.1
6	2	0	1771.1

6 iterations, total sum of distances = 1771.1

Notice that the total sum of distances decreases at each iteration as `kmeans` reassigns points between clusters and recomputes cluster centroids. In this case, the second phase of the algorithm did not make any reassignments, indicating that the first phase reached a minimum after five iterations. In some problems, the first phase might not reach a minimum, but the second phase always will.

A silhouette plot for this solution indicates that these four clusters are better separated than the three in the previous solution:

```
[silh4,h] = silhouette(X,idx4,'city');  
set(get(gca,'Children'),'FaceColor',[.8 .8 1])  
xlabel('Silhouette Value')  
ylabel('Cluster')
```

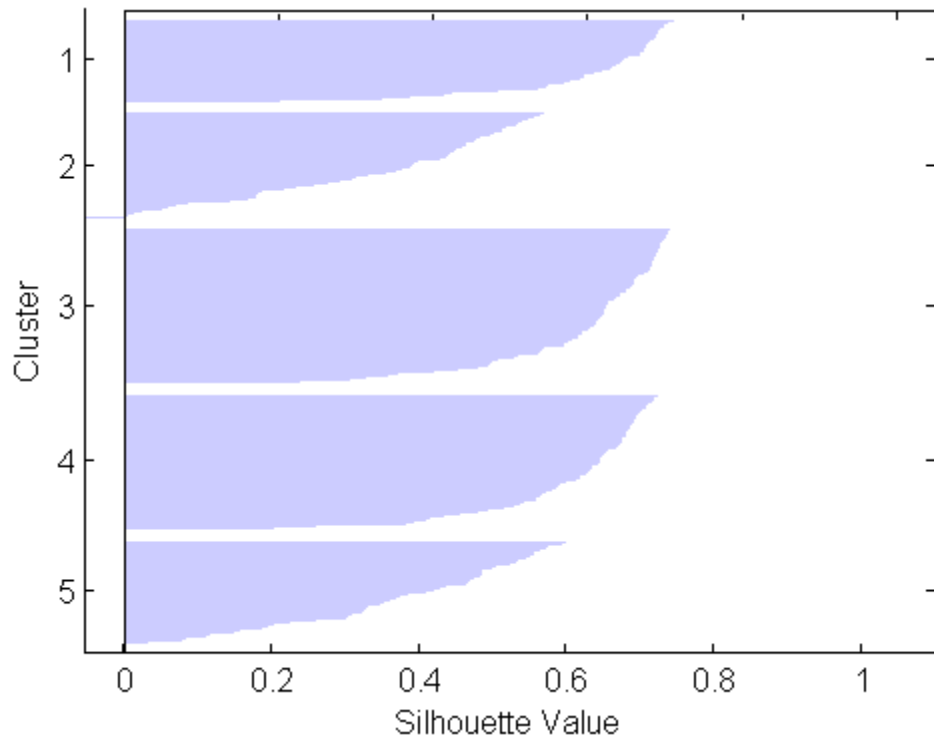
A more quantitative way to compare the two solutions is to look at the average silhouette values for the two cases:

```
mean(silh3)
ans =
    0.52594
mean(silh4)
ans =
    0.63997
```

Finally, try clustering the data using five clusters:

```
idx5 = kmeans(X,5,'dist','city','replicates',5);
[silh5,h] = silhouette(X,idx5,'city');
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
xlabel('Silhouette Value')
```

```
ylabel('Cluster')
mean(silh5)
ans =
    0.52657
```



This silhouette plot indicates that this is probably not the right number of clusters, since two of the clusters contain points with mostly low silhouette values. Without some knowledge of how many clusters are really in the data, it is a good idea to experiment with a range of values for k .

Avoid Local Minima

Like many other types of numerical minimizations, the solution that `kmeans` reaches often depends on the starting points. It is possible for `kmeans` to reach a local minimum, where reassigning any one point to a new cluster would increase the total sum of point-to-centroid distances, but where a

better solution does exist. However, you can use the optional 'replicates' parameter to overcome that problem.

For four clusters, specify five replicates, and use the 'display' parameter to print out the final sum of distances for each of the solutions.

```
[idx4,cent4,sumdist] = kmeans(X,4,'dist','city',...  
                             'display','final','replicates',5);  
17 iterations, total sum of distances = 2303.36  
5 iterations, total sum of distances = 1771.1  
6 iterations, total sum of distances = 1771.1  
5 iterations, total sum of distances = 1771.1  
8 iterations, total sum of distances = 2303.36
```

The output shows that, even for this relatively simple problem, non-global minima do exist. Each of these five replicates began from a different randomly selected set of initial centroids, and kmeans found two different local minima. However, the final solution that kmeans returns is the one with the lowest total sum of distances, over all replicates.

```
sum(sumdist)  
ans =  
    1771.1
```

Gaussian Mixture Models

In this section...

“Introduction to Gaussian Mixture Models” on page 11-28

“Cluster with Gaussian Mixtures” on page 11-28

Introduction to Gaussian Mixture Models

Gaussian mixture models are formed by combining multivariate normal density components.

In Statistics Toolbox software, use the `gmdistribution` class to fit data using an expectation maximization (EM) algorithm, which assigns posterior probabilities to each component density with respect to each observation.

Gaussian mixture models are often used for data clustering. Clusters are assigned by selecting the component that maximizes the posterior probability. Like k-means clustering, Gaussian mixture modeling uses an iterative algorithm that converges to a local optimum. Gaussian mixture modeling may be more appropriate than k-means clustering when clusters have different sizes and correlation within them. Clustering using Gaussian mixture models is sometimes considered a soft clustering method. The posterior probabilities for each point indicate that each data point has some probability of belonging to each cluster.

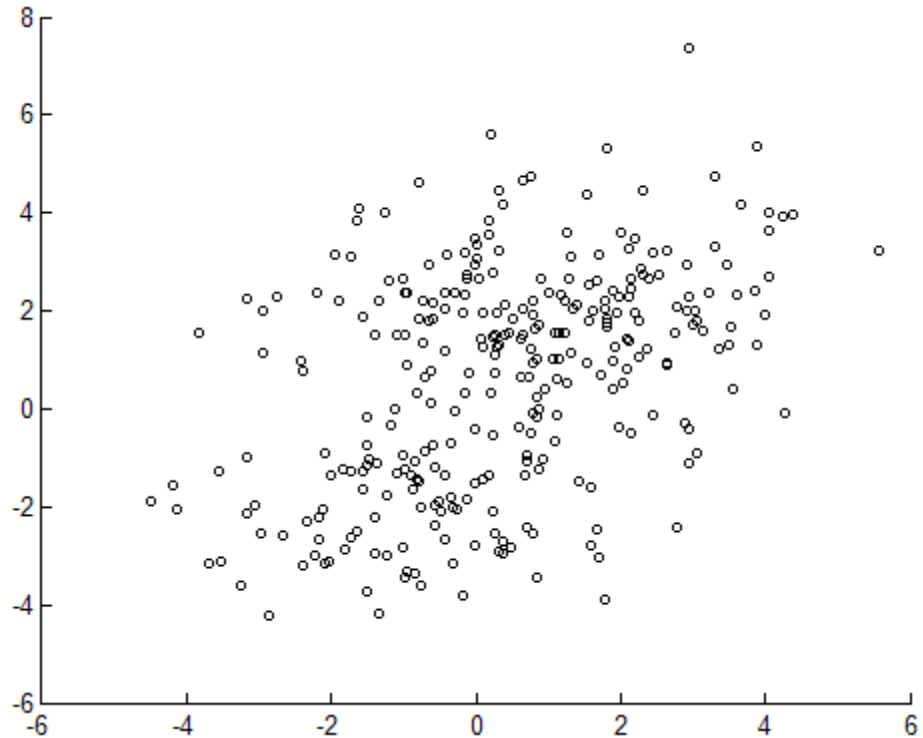
Cluster with Gaussian Mixtures

Gaussian mixture distributions can be used for clustering data, by realizing that the multivariate normal components of the fitted model can represent clusters.

- 1 To demonstrate the process, first generate some simulated data from a mixture of two bivariate Gaussian distributions using the `mvnrnd` function:

```
mu1 = [1 2];  
sigma1 = [3 .2; .2 2];  
mu2 = [-1 -2];  
sigma2 = [2 0; 0 1];
```

```
X = [mvnrnd(mu1,sigma1,200);mvnrnd(mu2,sigma2,100)];  
scatter(X(:,1),X(:,2),10,'ko')
```



- 2** Fit a two-component Gaussian mixture distribution. Here, you know the correct number of components to use. In practice, with real data, this decision would require comparing models with different numbers of components.

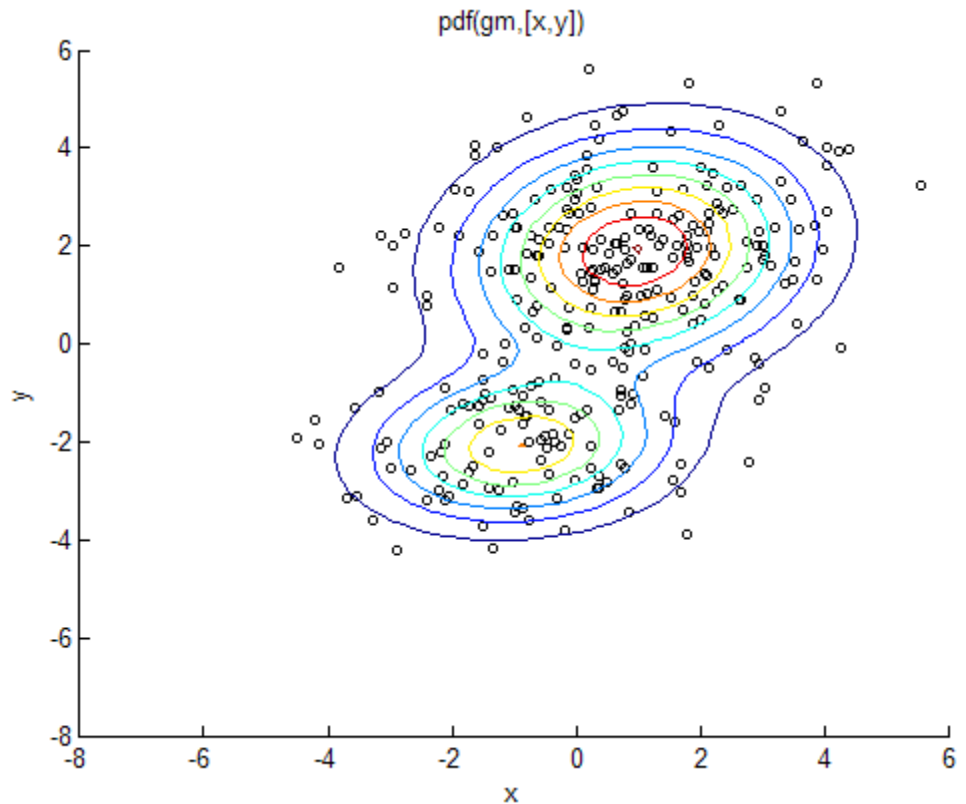
```
options = statset('Display','final');  
gm = gmdistribution.fit(X,2,'Options',options);
```

This displays

```
49 iterations, log-likelihood = -1207.91
```

- 3** Plot the estimated probability density contours for the two-component mixture distribution. The two bivariate normal components overlap, but their peaks are distinct. This suggests that the data could reasonably be divided into two clusters:

```
hold on
ezcontour(@(x,y)pdf(gm,[x y]),[-8 6],[-8 6]);
hold off
```

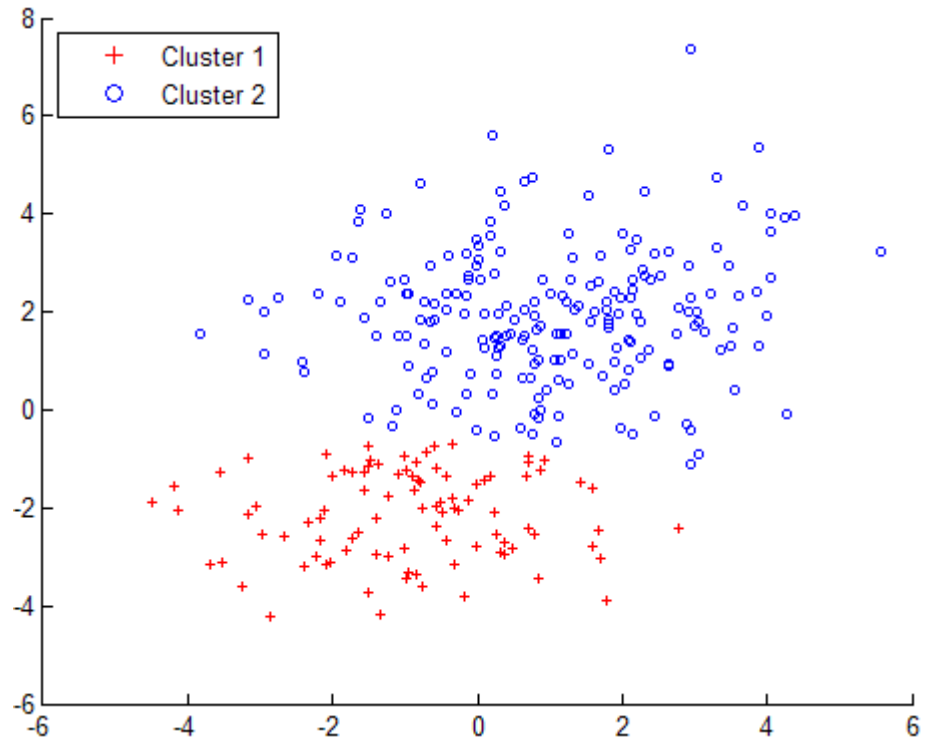


- 4** Partition the data into clusters using the `cluster` method for the fitted mixture distribution. The `cluster` method assigns each point to one of the two components in the mixture distribution.

```
idx = cluster(gm,X);
```

```
cluster1 = (idx == 1);
cluster2 = (idx == 2);

scatter(X(cluster1,1),X(cluster1,2),10,'r+');
hold on
scatter(X(cluster2,1),X(cluster2,2),10,'bo');
hold off
legend('Cluster 1','Cluster 2','Location','NW')
```



Each cluster corresponds to one of the bivariate normal components in the mixture distribution. `cluster` assigns points to clusters based on the estimated posterior probability that a point came from a component; each point is assigned to the cluster corresponding to the highest posterior probability. The posterior method returns those posterior probabilities.

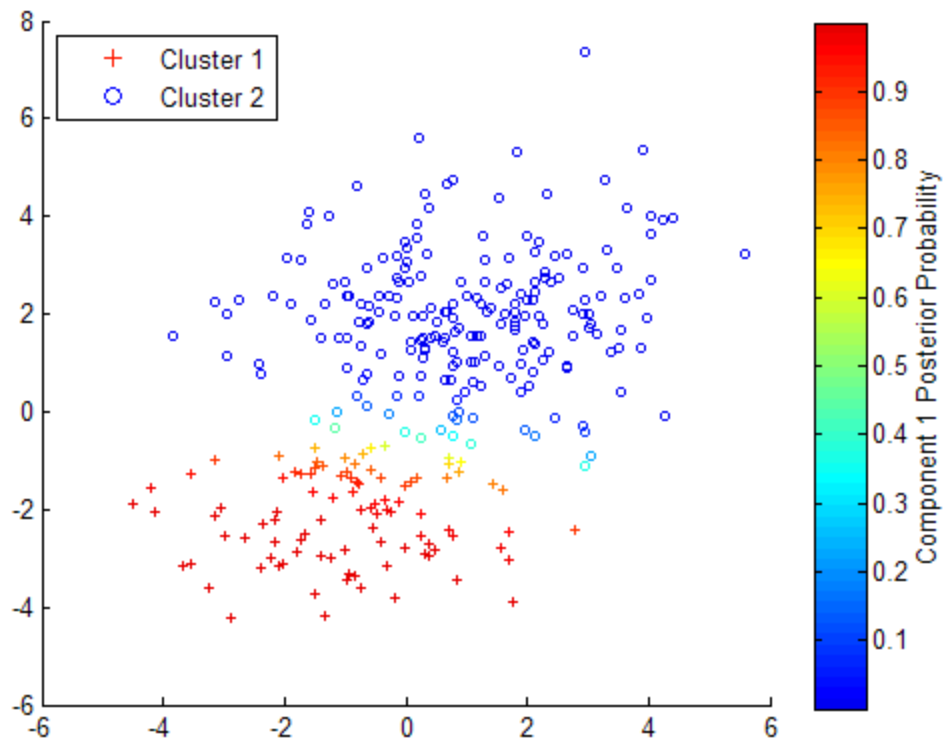
For example, plot the posterior probability of the first component for each point:

```

P = posterior(gm,X);

scatter(X(cluster1,1),X(cluster1,2),10,P(cluster1,1),'+')
hold on
scatter(X(cluster2,1),X(cluster2,2),10,P(cluster2,1),'o')
hold off
legend('Cluster 1','Cluster 2','Location','NW')
clrmap = jet(80); colormap(clrmap(9:72,:))
ylabel(colorbar,'Component 1 Posterior Probability')

```

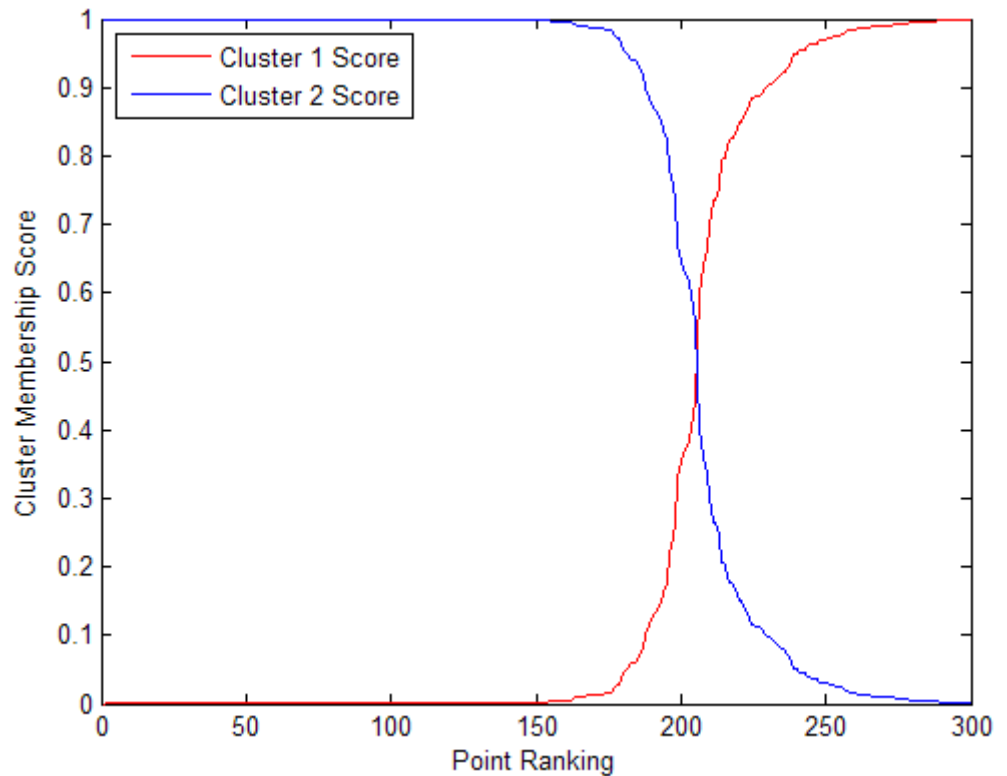


Soft Clustering Using Gaussian Mixture Distributions

An alternative to the previous example is to use the posterior probabilities for "soft clustering". Each point is assigned a membership score to each cluster. Membership scores are simply the posterior probabilities, and describe how similar each point is to each cluster's archetype, i.e., the mean of the

corresponding component. The points can be ranked by their membership score in a given cluster:

```
[~,order] = sort(P(:,1));  
plot(1:size(X,1),P(order,1),'r-',1:size(X,1),P(order,2),'b-');  
legend({'Cluster 1 Score' 'Cluster 2 Score'},'location','NW');  
ylabel('Cluster Membership Score');  
xlabel('Point Ranking');
```



Although a clear separation of the data is hard to see in a scatter plot of the data, plotting the membership scores indicates that the fitted distribution does a good job of separating the data into groups. Very few points have scores close to 0.5.

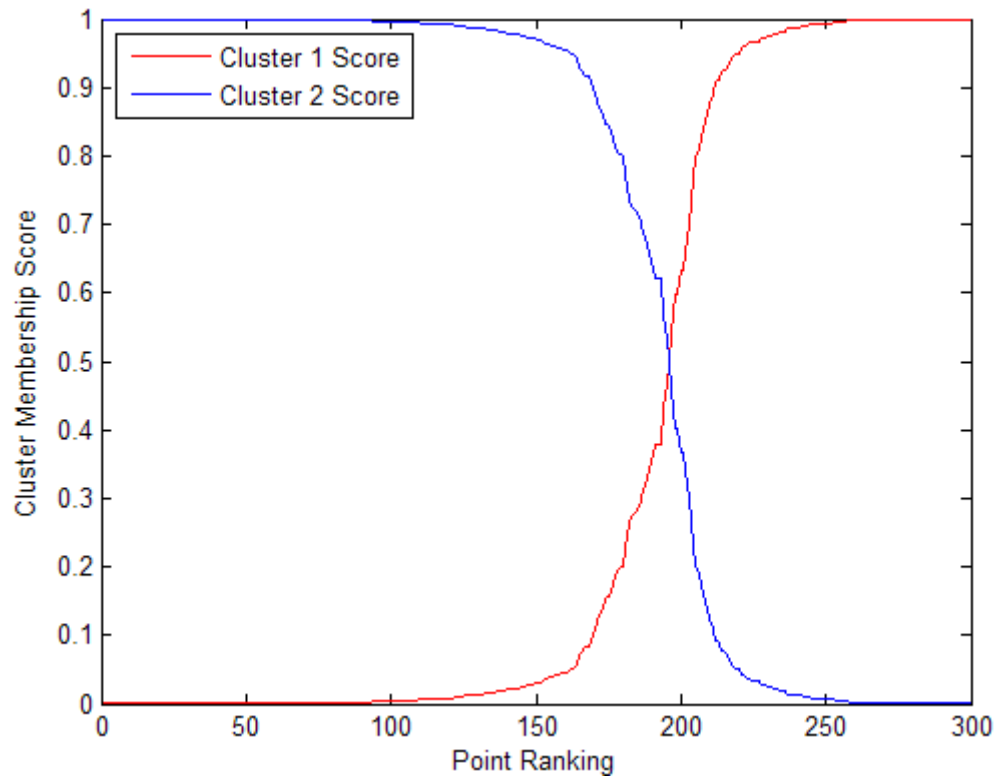
Soft clustering using a Gaussian mixture distribution is similar to fuzzy k-means clustering, which also assigns each point to each cluster with a membership score. The fuzzy k-means algorithm assumes that clusters are roughly spherical in shape, and all of roughly equal size. This is comparable to a Gaussian mixture distribution with a single covariance matrix that is shared across all components, and is a multiple of the identity matrix. In contrast, `gmdistribution` allows you to specify different covariance options. The default is to estimate a separate, unconstrained covariance matrix for each component. A more restricted option, closer to k-means, would be to estimate a shared, diagonal covariance matrix:

```
gm2 = gmdistribution.fit(X,2,'CovType','Diagonal',...  
    'SharedCov',true);
```

This covariance option is similar to fuzzy k-means clustering, but provides more flexibility by allowing unequal variances for different variables.

You can compute the soft cluster membership scores without computing hard cluster assignments, using `posterior`, or as part of hard clustering, as the second output from `cluster`:

```
P2 = posterior(gm2,X); % equivalently [idx,P2] = cluster(gm2,X)  
[~,order] = sort(P2(:,1));  
plot(1:size(X,1),P2(order,1),'r-',1:size(X,1),P2(order,2),'b-');  
legend({'Cluster 1 Score' 'Cluster 2 Score'},'location','NW');  
ylabel('Cluster Membership Score');  
xlabel('Point Ranking');
```



Assign New Data to Clusters

In the previous example, fitting the mixture distribution to data using `fit`, and clustering those data using `cluster`, are separate steps. However, the same data are used in both steps. You can also use the `cluster` method to assign new data points to the clusters (mixture components) found in the original data.

- 1 Given a data set X , first fit a Gaussian mixture distribution. The previous code has already done that.

```
gm
```

```
gm =
```

```
Gaussian mixture distribution with 2 components in 2 dimensions
```

```
Component 1:  
Mixing proportion: 0.312592  
Mean:    -0.9082   -2.1109
```

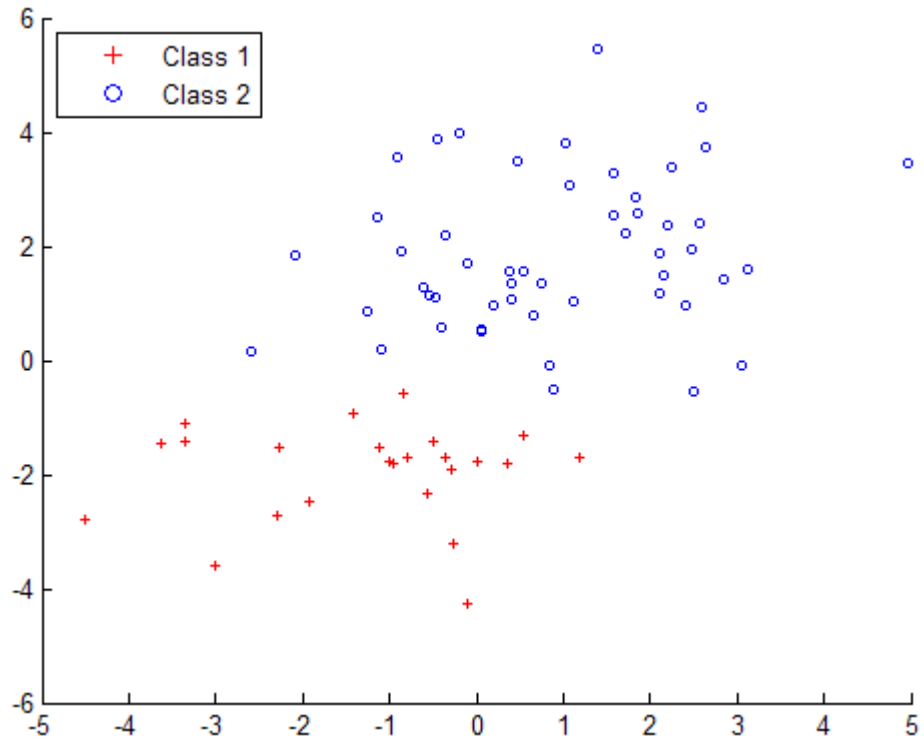
```
Component 2:  
Mixing proportion: 0.687408  
Mean:    0.9532    1.8940
```

- 2** You can then use `cluster` to assign each point in a new data set, `Y`, to one of the clusters defined for the original data:

```
Y = [mvnrnd(mu1,sigma1,50);mvnrnd(mu2,sigma2,25)];
```

```
idx = cluster(gm,Y);  
cluster1 = (idx == 1);  
cluster2 = (idx == 2);
```

```
scatter(Y(cluster1,1),Y(cluster1,2),10,'r+');  
hold on  
scatter(Y(cluster2,1),Y(cluster2,2),10,'bo');  
hold off  
legend('Class 1','Class 2','Location','NW')
```



As with the previous example, the posterior probabilities for each point can be treated as membership scores rather than determining "hard" cluster assignments.

For cluster to provide meaningful results with new data, Y should come from the same population as X , the original data used to create the mixture distribution. In particular, the estimated mixing probabilities for the Gaussian mixture distribution fitted to X are used when computing the posterior probabilities for Y .

Parametric Classification

- “Parametric Classification” on page 12-2
- “Discriminant Analysis” on page 12-3
- “Naive Bayes Classification” on page 12-36
- “Performance Curves” on page 12-39

Parametric Classification

Models of data with a categorical response are called *classifiers*. A classifier is built from *training data*, for which classifications are known. The classifier assigns new *test data* to one of the categorical levels of the response.

Parametric methods, like “Discriminant Analysis” on page 12-3, fit a parametric model to the training data and interpolate to classify test data.

Nonparametric methods, like classification and regression trees, use other means to determine classifications.

Discriminant Analysis

In this section...

“What Is Discriminant Analysis?” on page 12-3

“Create Discriminant Analysis Classifiers” on page 12-3

“Creating a Classifier Using ClassificationDiscriminant.fit” on page 12-4

“How the predict Method Classifies” on page 12-6

“Create and Visualize a Discriminant Analysis Classifier” on page 12-9

“Improve a Discriminant Analysis Classifier” on page 12-14

“Regularize a Discriminant Analysis Classifier” on page 12-22

“Examine the Gaussian Mixture Assumption” on page 12-29

“Bibliography” on page 12-35

What Is Discriminant Analysis?

Discriminant analysis is a classification method. It assumes that different classes generate data based on different Gaussian distributions.

- To train (create) a classifier, the fitting function estimates the parameters of a Gaussian distribution for each class (see “Creating a Classifier Using ClassificationDiscriminant.fit” on page 12-4).
- To predict the classes of new data, the trained classifier finds the class with the smallest misclassification cost (see “How the predict Method Classifies” on page 12-6).

Linear discriminant analysis is also known as the Fisher discriminant, named for its inventor, Sir R. A. Fisher [2].

Create Discriminant Analysis Classifiers

To create the basic types of discriminant analysis classifiers for the Fisher iris data:

- 1 Load the data:

```
load fisheriris;
```

- 2** Create a default (linear) discriminant analysis classifier:

```
linclass = ClassificationDiscriminant.fit(meas,species);
```

To visualize the classification boundaries of a 2-D linear classification of the data, see [Linear Discriminant Classification — Fisher Training Data](#) on page 12-12.

- 3** Classify an iris with average measurements:

```
meanmeas = mean(meas);  
meanclass = predict(linclass,meanmeas)
```

```
meanclass =  
    'versicolor'
```

- 4** Create a quadratic classifier:

```
quadclass = ClassificationDiscriminant.fit(meas,species,...  
    'discrimType','quadratic');
```

To visualize the classification boundaries of a 2-D quadratic classification of the data, see [Quadratic Discriminant Classification — Fisher Training Data](#) on page 12-14.

- 5** Classify an iris with average measurements using the quadratic classifier:

```
meanclass2 = predict(quadclass,meanmeas)
```

```
meanclass2 =  
    'versicolor'
```

Creating a Classifier Using `ClassificationDiscriminant.fit`

The model for discriminant analysis is:

- Each class (Y) generates data (X) using a multivariate normal distribution. In other words, the model assumes X has a Gaussian mixture distribution (gmdistribution).

- For linear discriminant analysis, the model has the same covariance matrix for each class; only the means vary.
- For quadratic discriminant analysis, both means and covariances of each class vary.

Under this modeling assumption, `ClassificationDiscriminant.fit` infers the mean and covariance parameters of each class.

- For linear discriminant analysis, it computes the sample mean of each class. Then it computes the sample covariance by first subtracting the sample mean of each class from the observations of that class, and taking the empirical covariance matrix of the result.
- For quadratic discriminant analysis, it computes the sample mean of each class. Then it computes the sample covariances by first subtracting the sample mean of each class from the observations of that class, and taking the empirical covariance matrix of each class.

The `fit` method does not use prior probabilities or costs for fitting.

Weighted Observations

The `fit` method constructs weighted classifiers using the following scheme. Suppose M is an N -by- K class membership matrix:

$$\begin{aligned} M_{nk} &= 1 \text{ if observation } n \text{ is from class } k \\ M_{nk} &= 0 \text{ otherwise.} \end{aligned}$$

The estimate of the class mean for unweighted data is

$$\hat{\mu}_k = \frac{\sum_{n=1}^N M_{nk} x_n}{\sum_{n=1}^N M_{nk}}.$$

For weighted data with positive weights w_n , the natural generalization is

$$\hat{\mu}_k = \frac{\sum_{n=1}^N M_{nk} w_n x_n}{\sum_{n=1}^N M_{nk} w_n}.$$

The unbiased estimate of the pooled-in covariance matrix for unweighted data is

$$\hat{\Sigma} = \frac{\sum_{n=1}^N \sum_{k=1}^K M_{nk} (x_n - \hat{\mu}_k)(x_n - \hat{\mu}_k)^T}{N - K}.$$

For quadratic discriminant analysis, the `fit` method uses $K = 1$.

For weighted data, assuming the weights sum to 1, the unbiased estimate of the pooled-in covariance matrix is

$$\hat{\Sigma} = \frac{\sum_{n=1}^N \sum_{k=1}^K M_{nk} w_n (x_n - \hat{\mu}_k)(x_n - \hat{\mu}_k)^T}{1 - \sum_{k=1}^K \frac{W_k^{(2)}}{W_k}},$$

where

- $W_k = \sum_{n=1}^N M_{nk} w_n$ is the sum of the weights for class k .
- $W_k^{(2)} = \sum_{n=1}^N M_{nk} w_n^2$ is the sum of squared weights per class.

How the predict Method Classifies

There are three elements in the `predict` classification algorithm:

- “Posterior Probability” on page 12-7
- “Prior Probability” on page 12-8
- “Cost” on page 12-8

`predict` classifies so as to minimize the expected classification cost:

$$\hat{y} = \arg \min_{y=1, \dots, K} \sum_{k=1}^K \hat{P}(k | x) C(y | k),$$

where

- \hat{y} is the predicted classification.
- K is the number of classes.
- $\hat{P}(k | x)$ is the posterior probability of class k for observation x .
- $C(y | k)$ is the cost of classifying an observation as y when its true class is k .

The space of X values divides into regions where a classification Y is a particular value. The regions are separated by straight lines for linear discriminant analysis, and by conic sections (ellipses, hyperbolas, or parabolas) for quadratic discriminant analysis. For a visualization of these regions, see “Create and Visualize a Discriminant Analysis Classifier” on page 12-9.

Posterior Probability

The posterior probability that a point x belongs to class k is the product of the prior probability and the multivariate normal density. The density function of the multivariate normal with mean μ_k and covariance Σ_k at a point x is

$$P(x | k) = \frac{1}{(2\pi |\Sigma_k|)^{1/2}} \exp\left(-\frac{1}{2}(x - \mu_k)^T \Sigma_k^{-1} (x - \mu_k)\right),$$

where $|\Sigma_k|$ is the determinant of Σ_k , and Σ_k^{-1} is the inverse matrix.

Let $P(k)$ represent the prior probability of class k . Then the posterior probability that an observation x is of class k is

$$\hat{P}(k | x) = \frac{P(x | k)P(k)}{P(x)},$$

where $P(x)$ is a normalization constant, namely, the sum over k of $P(x|k)P(k)$.

Prior Probability

The prior probability is one of three choices:

- 'uniform' — The prior probability of class k is 1 over the total number of classes.
- 'empirical' — The prior probability of class k is the number of training samples of class k divided by the total number of training samples.
- A numeric vector — The prior probability of class k is the j th element of the prior vector. See `ClassificationDiscriminant.fit`.

After creating a classifier `obj`, you can set the prior using dot addressing:

```
obj.Prior = v;
```

where v is a vector of positive elements representing the frequency with which each element occurs. You do not need to retrain the classifier when you set a new prior.

Cost

There are two costs associated with discriminant analysis classification: the true misclassification cost per class, and the expected misclassification cost per observation.

True Misclassification Cost per Class. $\text{Cost}(i, j)$ is the cost of classifying an observation into class j if its true class is i . By default, $\text{Cost}(i, j)=1$ if $i \neq j$, and $\text{Cost}(i, j)=0$ if $i=j$. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

You can set any cost matrix you like when creating a classifier. Pass the cost matrix in the `Cost` name-value pair in `ClassificationDiscriminant.fit`.

After you create a classifier `obj`, you can set a custom cost using dot addressing:

```
obj.Cost = B;
```

B is a square matrix of size K -by- K when there are K classes. You do not need to retrain the classifier when you set a new cost.

Expected Misclassification Cost per Observation. Suppose you have N_{obs} observations that you want to classify with a trained discriminant analysis classifier `obj`. Suppose you have K classes. You place the observations into a matrix X_{new} with one observation per row. The command

```
[label,score,cost] = predict(obj,Xnew)
```

returns, among other outputs, a cost matrix of size N_{obs} -by- K . Each row of the cost matrix contains the expected (average) cost of classifying the observation into each of the K classes. `cost(n,k)` is

$$\sum_{i=1}^K \hat{P}(i | X_{\text{new}}(n)) C(k | i),$$

where

- K is the number of classes.
- $\hat{P}(i | X_{\text{new}}(n))$ is the posterior probability of class i for observation $X_{\text{new}}(n)$.
- $C(k | i)$ is the cost of classifying an observation as k when its true class is i .

Create and Visualize a Discriminant Analysis Classifier

This example shows both linear and quadratic classification of the Fisher iris data. The example uses only two of the four predictors to enable simple plotting.

1 Load the data:

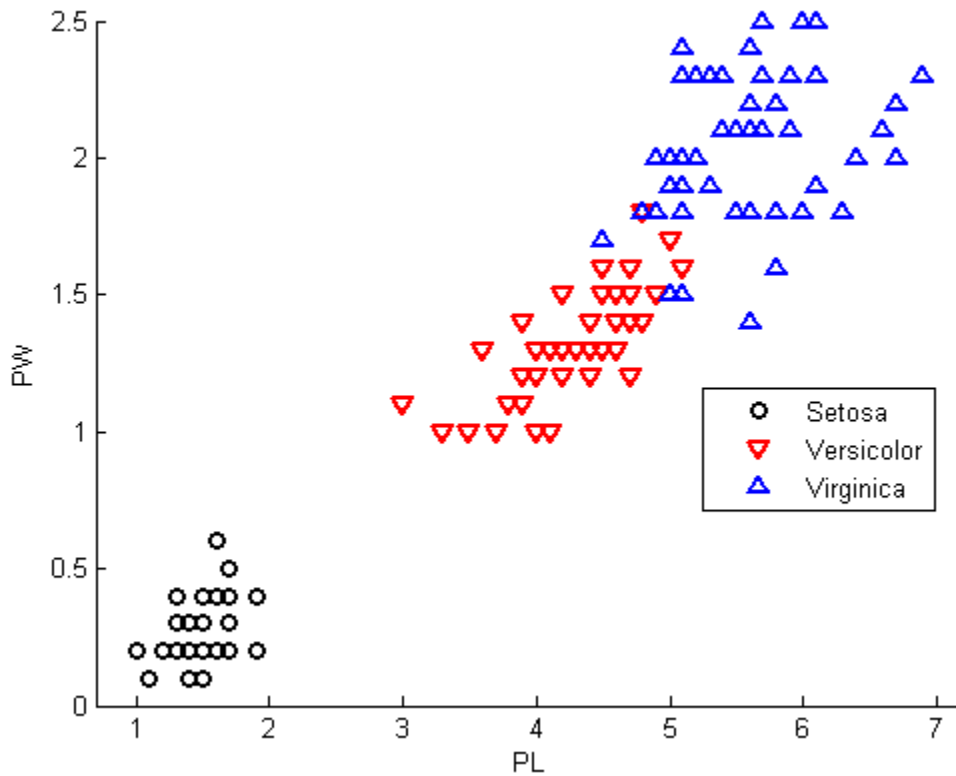
```
load fisheriris
```

2 Use the petal length (PL) and petal width (PW) measurements:

```
PL = meas(:,3);
PW = meas(:,4);
```

3 Plot the data, showing the classification:

```
h1 = gscatter(PL,PW,species,'krb','ov^',[],'off');
set(h1,'LineWidth',2)
legend('Setosa','Versicolor','Virginica',...
      'Location','best')
```



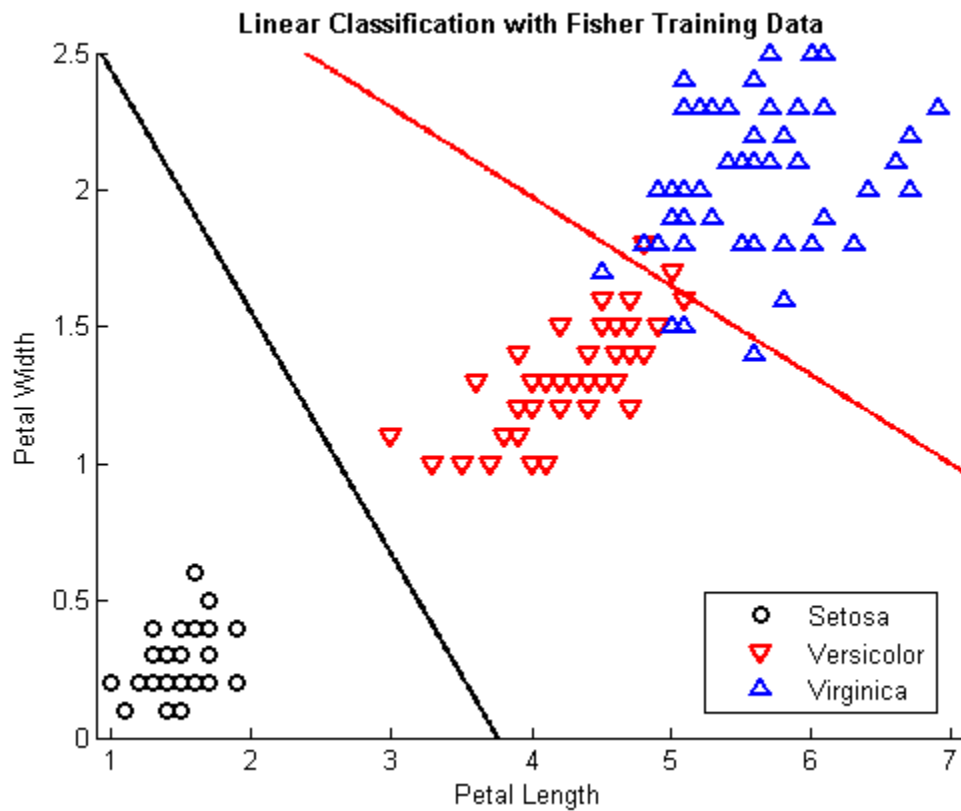
4 Create a linear classifier:

```
X = [PL,PW];
cls = ClassificationDiscriminant.fit(X,species);
```

5 Plot the classification boundaries:


```
hold on
K = cls.Coeffs(2,3).Const;
L = cls.Coeffs(2,3).Linear;
% Plot the curve  $K + [x,y]*L = 0$ :
f = @(x1,x2) K + L(1)*x1 + L(2)*x2;
h2 = ezplot(f,[.9 7.1 0 2.5]);
set(h2,'Color','r','LineWidth',2)

K = cls.Coeffs(1,2).Const;
L = cls.Coeffs(1,2).Linear;
% Plot the curve  $K + [x1,x2]*L = 0$ :
f = @(x1,x2) K + L(1)*x1 + L(2)*x2;
h3 = ezplot(f,[.9 7.1 0 2.5]);
set(h3,'Color','k','LineWidth',2)
axis([.9 7.1 0 2.5])
xlabel('Petal Length')
ylabel('Petal Width')
title('\bf Linear Classification with Fisher Training Data')
```



Linear Discriminant Classification – Fisher Training Data

- 6 Create a quadratic discriminant classifier:

```
cqs = ClassificationDiscriminant.fit(X,species,...
    'DiscrimType','quadratic');
```

- 7 Plot the classification boundaries:

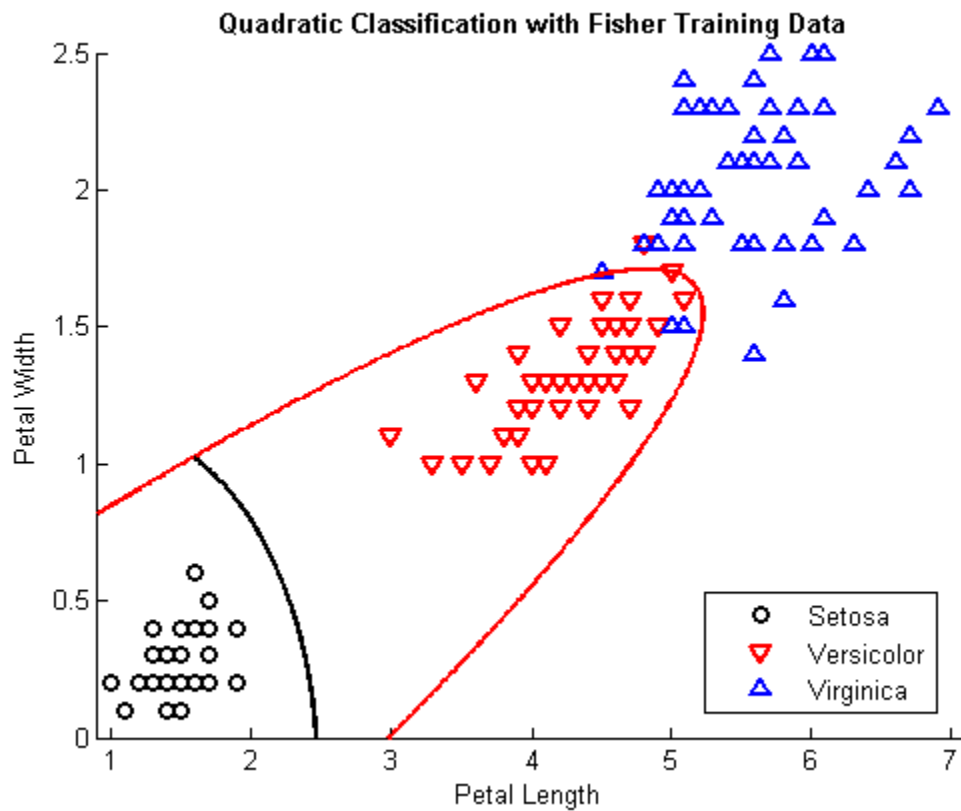
```
delete(h2); delete(h3) % remove the linear plots
K = cqs.Coeffs(2,3).Const;
L = cqs.Coeffs(2,3).Linear;
Q = cqs.Coeffs(2,3).Quadratic;
% Plot the curve  $K + [x1,x2]*L + [x1,x2]*Q*[x1,x2]^T=0$ :
```

```

f = @(x1,x2) K + L(1)*x1 + L(2)*x2 + Q(1,1)*x1.^2 + ...
      (Q(1,2)+Q(2,1))*x1.*x2 + Q(2,2)*x2.^2;
h2 = ezplot(f,[.9 7.1 0 2.5]);
set(h2,'Color','r','LineWidth',2)

K = cqs.Coeffs(1,2).Const;
L = cqs.Coeffs(1,2).Linear;
Q = cqs.Coeffs(1,2).Quadratic;
% Plot the curve K + [x1,x2]*L + [x1,x2]*Q*[x1,x2]'=0:
f = @(x1,x2) K + L(1)*x1 + L(2)*x2 + Q(1,1)*x1.^2 + ...
      (Q(1,2)+Q(2,1))*x1.*x2 + Q(2,2)*x2.^2;
h3 = ezplot(f,[.9 7.1 0 1.02]); % plot the relevant
                                % portion of the curve
set(h3,'Color','k','LineWidth',2)
axis([.9 7.1 0 2.5])
xlabel('Petal Length')
ylabel('Petal Width')
title('{\bf Quadratic Classification with Fisher Training Data}')
hold off

```



Quadratic Discriminant Classification – Fisher Training Data

Improve a Discriminant Analysis Classifier

- “Deal with Singular Data” on page 12-15
- “Choose a Discriminant Type” on page 12-16
- “Examine the Resubstitution Error and Confusion Matrix” on page 12-17
- “Cross Validation” on page 12-18
- “Change Costs and Priors” on page 12-19

Deal with Singular Data

Discriminant analysis needs data sufficient to fit Gaussian models with invertible covariance matrices. If your data is not sufficient to fit such a model uniquely, `ClassificationDiscriminant.fit` fails. This section shows methods for handling failures.

Tip To obtain a discriminant analysis classifier without failure, set the `DiscrimType` name-value pair to `'pseudoLinear'` or `'pseudoQuadratic'` in `ClassificationDiscriminant.fit`.

“Pseudo” discriminants never fail, because they use the pseudoinverse of the covariance matrix Σ_k (see `pinv`).

Example: Singular Covariance Matrix. When the covariance matrix of the fitted classifier is singular, `ClassificationDiscriminant.fit` can fail:

```
load popcorn
X = popcorn(:,[1 2]);
X(:,3) = 0; % a zero-variance column
Y = popcorn(:,3);
ppcrn = ClassificationDiscriminant.fit(X,Y);

Error using ClassificationDiscriminant (line 635)
Predictor x3 has zero variance. Either exclude this predictor or set 'discrimType' to
'pseudoLinear' or 'diagLinear'.

Error in classreg.learning.FitTemplate/fit (line 243)
    obj = this.MakeFitObject(X,Y,W,this.ModelParams,fitArgs{:});

Error in ClassificationDiscriminant.fit (line 296)
    this = fit(temp,X,Y);
```

To proceed with linear discriminant analysis, use a `pseudoLinear` or `diagLinear` discriminant type:

```
ppcrn = ClassificationDiscriminant.fit(X,Y,...
    'discrimType','pseudoLinear');
meanpredict = predict(ppcrn,mean(X))
```

```
meanpredict =  
    3.5000
```

Choose a Discriminant Type

There are six types of discriminant analysis classifiers: linear and quadratic, with *diagonal* and *pseudo* variants of each type.

Tip To see if your covariance matrix is singular, set `discrimType` to 'linear' or 'quadratic'. If the matrix is singular, the `ClassificationDiscriminant.fit` method fails for 'quadratic', and the `Gamma` property is nonzero for 'linear'.

To obtain a quadratic classifier even when your covariance matrix is singular, set `discrimType` to 'pseudoQuadratic' or 'diagQuadratic'.

```
obj = ClassificationDiscriminant.fit(X,Y,...  
    'discrimType','pseudoQuadratic') % or 'diagQuadratic'
```

Choose a classifier type by setting the `discrimType` name-value pair to one of:

- 'linear' (default) — Estimate one covariance matrix for all classes.
- 'quadratic' — Estimate one covariance matrix for each class.
- 'diagLinear' — Use the diagonal of the 'linear' covariance matrix, and use its pseudoinverse if necessary.
- 'diagQuadratic' — Use the diagonals of the 'quadratic' covariance matrices, and use their pseudoinverses if necessary.
- 'pseudoLinear' — Use the pseudoinverse of the 'linear' covariance matrix if necessary.
- 'pseudoQuadratic' — Use the pseudoinverses of the 'quadratic' covariance matrices if necessary.

`ClassificationDiscriminant.fit` can fail for the 'linear' and 'quadratic' classifiers. When it fails, it returns an explanation, as shown in “Deal with Singular Data” on page 12-15.

`ClassificationDiscriminant.fit` always succeeds with the diagonal and pseudo variants. For information about pseudoinverses, see `pinv`.

You can set the discriminant type using dot addressing after constructing a classifier:

```
obj.DiscrimType = 'discrimType'
```

You can change between linear types or between quadratic types, but cannot change between a linear and a quadratic type.

Examine the Resubstitution Error and Confusion Matrix

The *resubstitution error* is the difference between the response training data and the predictions the classifier makes of the response based on the input training data. If the resubstitution error is high, you cannot expect the predictions of the classifier to be good. However, having low resubstitution error does not guarantee good predictions for new data. Resubstitution error is often an overly optimistic estimate of the predictive error on new data.

The *confusion matrix* shows how many errors, and which types, arise in resubstitution. When there are K classes, the confusion matrix R is a K -by- K matrix with

$R(i, j)$ = the number of observations of class i that the classifier predicts to be of class j .

Example: Resubstitution Error of a Discriminant Analysis Classifier.

Examine the resubstitution error of the default discriminant analysis classifier for the Fisher iris data:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
resuberror = resubLoss(obj)

resuberror =
    0.0200
```

The resubstitution error is very low, meaning `obj` classifies nearly all the Fisher iris data correctly. The total number of misclassifications is:

```
resuberror * obj.NObservations  
  
ans =  
    3.0000
```

To see the details of the three misclassifications, examine the confusion matrix:

```
R = confusionmat(obj.Y,resubPredict(obj))  
  
R =  
    50     0     0  
     0    48     2  
     0     1    49
```

```
obj.ClassNames
```

```
ans =  
    'setosa'  
    'versicolor'  
    'virginica'
```

- $R(1,:) = [50 \ 0 \ 0]$ means `obj` classifies all 50 setosa irises correctly.
- $R(2,:) = [0 \ 48 \ 2]$ means `obj` classifies 48 versicolor irises correctly, and misclassifies two versicolor irises as virginica.
- $R(3,:) = [0 \ 1 \ 49]$ means `obj` classifies 49 virginica irises correctly, and misclassifies one virginica iris as versicolor.

Cross Validation

Typically, discriminant analysis classifiers are robust and do not exhibit overtraining when the number of predictors is much less than the number of observations. Nevertheless, it is good practice to cross validate your classifier to ensure its stability.

Example: Cross Validating a Discriminant Analysis Classifier. Try five-fold cross validation of a quadratic discriminant analysis classifier:

- 1 Load the Fisher iris data:

```
load fisheriris
```

- 2 Create a quadratic discriminant analysis classifier for the data:

```
quadisc = ClassificationDiscriminant.fit(meas,species,...  
    'DiscrimType','quadratic');
```

- 3 Find the resubstitution error of the classifier:

```
qerror = resubLoss(quadisc)
```

```
qerror =  
    0.0200
```

The classifier does an excellent job. Nevertheless, resubstitution error can be an optimistic estimate of the error when classifying new data. So proceed to cross validation.

- 4 Create a cross-validation model:

```
cvmodel = crossval(quadisc,'kfold',5);
```

- 5 Find the cross-validation loss for the model, meaning the error of the out-of-fold observations:

```
cverror = kfoldLoss(cvmodel)
```

```
cverror =  
    0.0333
```

The cross-validated loss is nearly as low as the original resubstitution loss. Therefore, you can have confidence that the classifier is reasonably accurate.

Change Costs and Priors

Sometimes you want to avoid certain misclassification errors more than others. For example, it might be better to have oversensitive cancer detection instead of undersensitive cancer detection. Oversensitive detection gives more false positives (unnecessary testing or treatment). Undersensitive detection gives more false negatives (preventable illnesses or deaths). The

consequences of underdetection can be high. Therefore, you might want to set costs to reflect the consequences.

Similarly, the training data Y can have a distribution of classes that does not represent their true frequency. If you have a better estimate of the true frequency, you can include this knowledge in the classification prior property.

Example: Setting Custom Misclassification Costs. Consider the Fisher iris data. Suppose that the cost of classifying a versicolor iris as virginica is 10 times as large as making any other classification error. Create a classifier from the data, then incorporate this cost and then view the resulting classifier.

- 1 Load the Fisher iris data and create a default (linear) classifier as in “Example: Resubstitution Error of a Discriminant Analysis Classifier” on page 12-17:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
resuberror = resubLoss(obj)
```

```
resuberror =
    0.0200
```

```
R = confusionmat(obj.Y,resubPredict(obj))
```

```
R =
    50     0     0
     0    48     2
     0     1    49
```

```
obj.ClassNames
```

```
ans =
    'setosa'
    'versicolor'
    'virginica'
```

$R(2,:) = [0 \ 48 \ 2]$ means obj classifies 48 versicolor irises correctly, and misclassifies two versicolor irises as virginica.

- 2** Change the cost matrix to make fewer mistakes in classifying versicolor irises as virginica:

```
obj.Cost(2,3) = 10;
R2 = confusionmat(obj.Y,resubPredict(obj))
```

```
R2 =
    50     0     0
     0    50     0
     0     7    43
```

obj now classifies all versicolor irises correctly, at the expense of increasing the number of misclassifications of virginica irises from 1 to 7.

Example: Setting Alternative Priors. Consider the Fisher iris data. There are 50 irises of each kind in the data. Suppose that, in a particular region, you have historical data that shows virginica are five times as prevalent as the other kinds. Create a classifier that incorporates this information.

- 1** Load the Fisher iris data and make a default (linear) classifier as in “Example: Resubstitution Error of a Discriminant Analysis Classifier” on page 12-17:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
resuberror = resubLoss(obj)
```

```
resuberror =
    0.0200
```

```
R = confusionmat(obj.Y,resubPredict(obj))
```

```
R =
    50     0     0
     0    48     2
     0     1    49
```

```
obj.ClassNames
```

```
ans =
    'setosa'
    'versicolor'
```

```
'virginica'
```

`R(3,:) = [0 1 49]` means `obj` classifies 49 virginica irises correctly, and misclassifies one virginica iris as versicolor.

- 2 Change the prior to match your historical data, and examine the confusion matrix of the new classifier:

```
obj.Prior = [1 1 5];  
R2 = confusionmat(obj.Y,resubPredict(obj))
```

```
R2 =  
    50     0     0  
     0    46     4  
     0     0    50
```

The new classifier classifies all virginica irises correctly, at the expense of increasing the number of misclassifications of versicolor irises from 2 to 4.

Regularize a Discriminant Analysis Classifier

To make a more robust and simpler model, try to remove predictors from your model without hurting its predictive power. This is especially important when you have many predictors in your data. Linear discriminant analysis uses the two regularization parameters, `Gamma` and `Delta`, to identify and remove redundant predictors. The `cvshrink` method helps you identify appropriate settings for these parameters.

1. Load data and create a classifier.

Create a linear discriminant analysis classifier for the ovariancancer data. Set the `SaveMemory` and `FillCoeffs` options to keep the resulting model reasonably small.

```
load ovariancancer  
obj = ClassificationDiscriminant.fit(obs,grp,...  
    'SaveMemory','on','FillCoeffs','off');
```

2. Cross validate the classifier.

Use 30 levels of Gamma and 30 levels of Delta to search for good parameters. This search is time consuming. Set Verbose to 1 to view the progress.

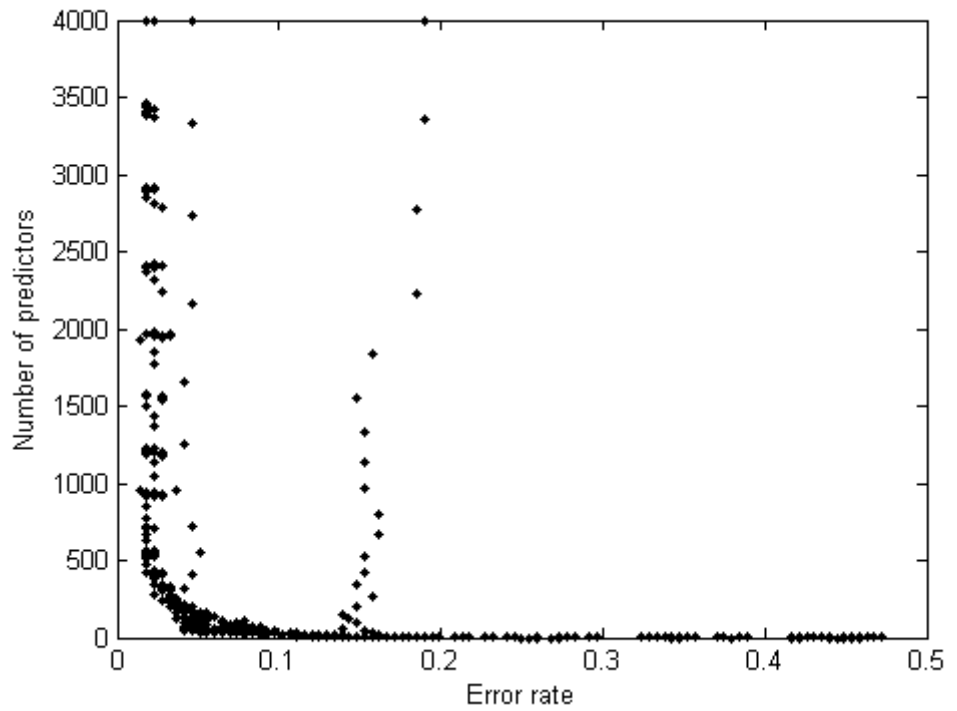
```
rng(8000,'twister') % for reproducibility
[err,gamma,delta,numpred] = cvshrink(obj,...
    'NumGamma',29,'NumDelta',29,'Verbose',1);
```

```
Done building cross-validated model.
Processing Gamma step 1 out of 30.
Processing Gamma step 2 out of 30.
Processing Gamma step 3 out of 30.
%%% (many lines removed) %%%
Processing Gamma step 28 out of 30.
Processing Gamma step 29 out of 30.
Processing Gamma step 30 out of 30.
```

3. Examine the quality of the regularized classifiers.

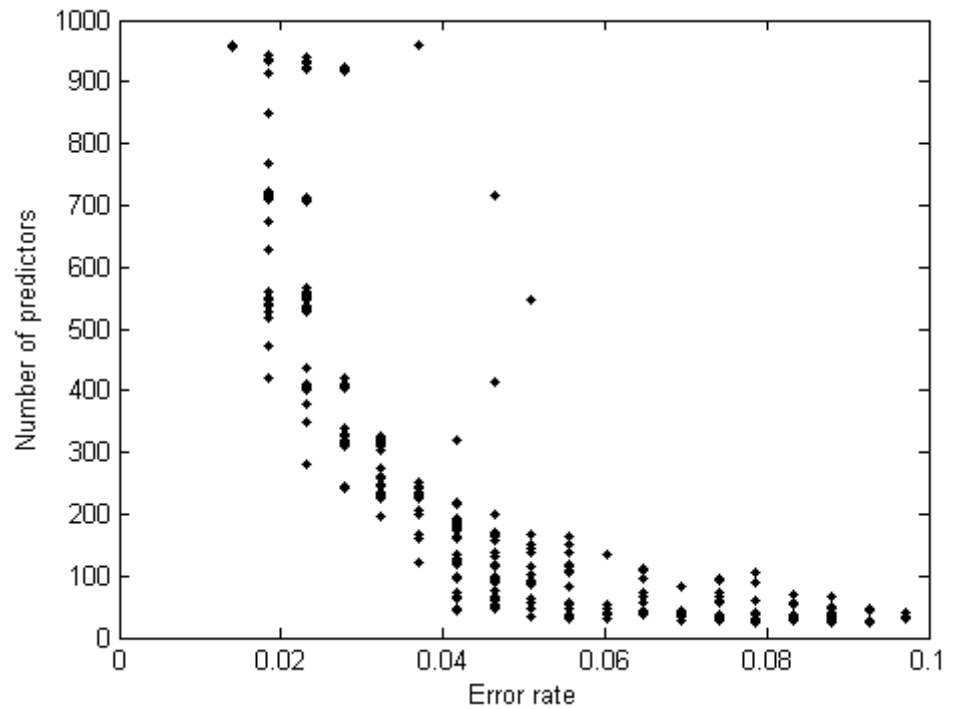
Plot the number of predictors against the error.

```
figure;
plot(err,numpred,'k.')
xlabel('Error rate');
ylabel('Number of predictors');
```



Examine the lower-left part of the plot more closely.

```
axis([0 .1 0 1000])
```



There is a clear tradeoff between lower number of predictors and lower error.

4. Choose an optimal tradeoff between model size and accuracy.

Find the values of Gamma and Delta that give minimal error.

```
minerr = min(min(err));
[p,q] = find(err == minerr)
```

p =

24

25

q =

8

8

Two points have the same minimal error: [24,8] and [25,8], which correspond to

```
[gamma(p(1)),delta(p(1),q(1))]
```

```
ans =  
    0.8436    0.1463
```

```
[gamma(p(2)),delta(p(2),q(2))]
```

```
ans =  
    0.8697    0.1425
```

These points correspond to about a quarter of the total predictors having nonzero coefficients in the model.

```
numpred(p(1),q(1))
```

```
ans =  
    957
```

```
numpred(p(2),q(2))
```

```
ans =  
    960
```

To further lower the number of predictors, you must accept larger error rates. For example, to choose the Gamma and Delta that give the lowest error rate with 250 or fewer predictors:

```
low250 = min(min(err(numpred <= 250)))
```

```
low250 =  
  
    0.0278
```

```
lownum = min(min(numpred(err == low250)))
```

```
lownum =  
  
    243
```


You need 243 predictors to achieve an error rate of 0.0278, and this is the lowest error rate among those that have 250 predictors or fewer. The Gamma and Delta that achieve this error/number of predictors:

```
[r,s] = find((err == low250) & (numpred == lownum));
gamma(r)
```

```
ans =
```

```
0.7133
```

```
delta(r,s)
```

```
ans =
```

```
0.2960
```

5. Set the regularization parameters.

To set the classifier with these values of Gamma and Delta, use dot addressing.

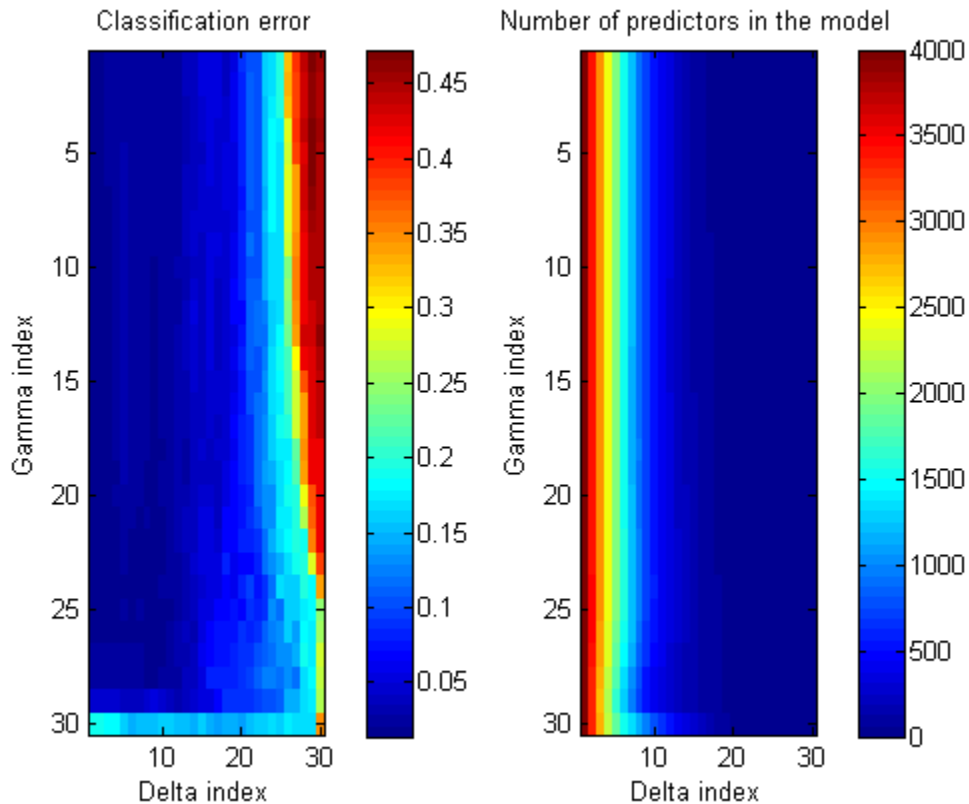
```
obj.Gamma = gamma(r);
obj.Delta = delta(r,s);
```

6. Heat map plot.

To compare the `cvshrink` calculation to that in Guo, Hastie, and Tibshirani [3], plot heat maps of error and number of predictors against Gamma and the index of the Delta parameter. (The Delta parameter range depends on the value of the Gamma parameter. So to get a rectangular plot, use the Delta index, not the parameter itself.)

```
% First create the Delta index matrix
indx = repmat(1:size(delta,2),size(delta,1),1);
figure
subplot(1,2,1)
imagesc(err);
colorbar;
title('Classification error');
xlabel('Delta index');
ylabel('Gamma index');
```

```
subplot(1,2,2)
imagesc(numpred);
colorbar;
title('Number of predictors in the model');
xlabel('Delta index');
ylabel('Gamma index');
```



You see the best classification error when Delta is small, but fewest predictors when Delta is large.

Examine the Gaussian Mixture Assumption

Discriminant analysis assumes that the data comes from a Gaussian mixture model (see “Creating a Classifier Using `ClassificationDiscriminant.fit`” on page 12-4). If the data appears to come from a Gaussian mixture model, you can expect discriminant analysis to be a good classifier. Furthermore, the default linear discriminant analysis assumes that all class covariance matrices are equal. This section shows methods to check these assumptions:

- “Bartlett Test of Equal Covariance Matrices for Linear Discriminant Analysis” on page 12-29
- “Q-Q Plot” on page 12-31
- “Mardia Kurtosis Test of Multivariate Normality” on page 12-34

Bartlett Test of Equal Covariance Matrices for Linear Discriminant Analysis

The Bartlett test (see Box [1]) checks equality of the covariance matrices of the various classes. If the covariance matrices are equal, the test indicates that linear discriminant analysis is appropriate. If not, consider using quadratic discriminant analysis, setting the `DiscrimType` name-value pair to 'quadratic' in `ClassificationDiscriminant.fit`.

The Bartlett test assumes normal (Gaussian) samples, where neither the means nor covariance matrices are known. To determine whether the covariances are equal, compute the following quantities:

- Sample covariance matrices per class σ_i , $1 \leq i \leq k$, where k is the number of classes.
- Pooled-in covariance matrix σ .
- Test statistic V :

$$V = (n - k) \log(|\Sigma|) - \sum_{i=1}^k (n_i - 1) \log(|\Sigma_i|)$$

where n is the total number of observations, and n_i is the number of observations in class i , and $|\Sigma|$ means the determinant of the matrix Σ .

- Asymptotically, as the number of observations in each class n_i become large, V is distributed approximately χ^2 with $kd(d+1)/2$ degrees of freedom, where d is the number of predictors (number of dimensions in the data).

The Bartlett test is to check whether V exceeds a given percentile of the χ^2 distribution with $kd(d+1)/2$ degrees of freedom. If it does, then reject the hypothesis that the covariances are equal.

Example: Bartlett Test for Equal Covariance Matrices. Check whether the Fisher iris data is well modeled by a single Gaussian covariance, or whether it would be better to model it as a Gaussian mixture.

```
load fisheriris;
prednames = {'SepalLength','SepalWidth',...
             'PetalLength','PetalWidth'};
L = ClassificationDiscriminant.fit(meas,species,...
    'PredictorNames',prednames);
Q = ClassificationDiscriminant.fit(meas,species,...
    'PredictorNames',prednames,'DiscrimType','quadratic');
D = 4; % Number of dimensions of X
Nclass = [50 50 50];
N = L.NObservations;
K = numel(L.ClassNames);
SigmaQ = Q.Sigma;
SigmaL = L.Sigma;
logV = (N-K)*log(det(SigmaL));
for k=1:K
    logV = logV - (Nclass(k)-1)*log(det(SigmaQ(:,:,k)));
end
nu = (K-1)*D*(D+1)/2;
pval = 1-chi2cdf(logV,nu)

pval =
    0
```

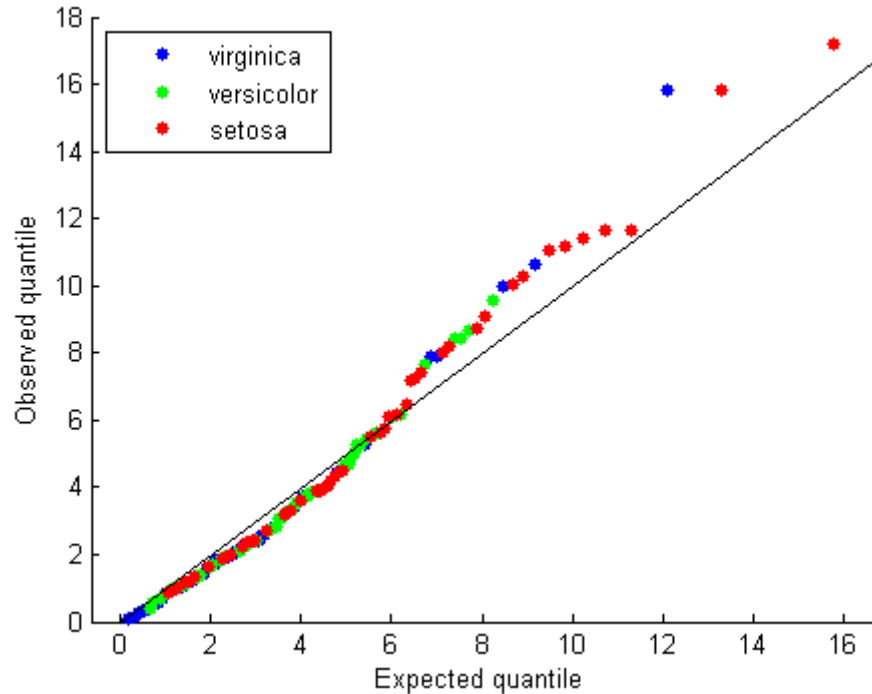
The Bartlett test emphatically rejects the hypothesis of equal covariance matrices. If $pval$ had been greater than 0.05, the test would not have rejected the hypothesis. The result indicates to use quadratic discriminant analysis, as opposed to linear discriminant analysis.

Q-Q Plot

A Q-Q plot graphically shows whether an empirical distribution is close to a theoretical distribution. If the two are equal, the Q-Q plot lies on a 45° line. If not, the Q-Q plot strays from the 45° line.

Check Q-Q Plots for Linear and Quadratic Discriminants. For linear discriminant analysis, use a single covariance matrix for all classes.

```
load fisheriris;
prednames = {'SepalLength', 'SepalWidth', ...
            'PetalLength', 'PetalWidth'};
L = ClassificationDiscriminant.fit(meas, species, ...
    'PredictorNames', prednames);
N = L.NObservations;
K = numel(L.ClassNames);
mahL = mahal(L, L.X, 'ClassLabels', L.Y);
D = 4;
expQ = chi2inv(((1:N)-0.5)/N, D); % expected quantiles
[mahL, sorted] = sort(mahL); % sorted observed quantiles
figure;
gscatter(expQ, mahL, L.Y(sorted), 'bgr', [], [], 'off');
legend('virginica', 'versicolor', 'setosa', 'Location', 'NW');
xlabel('Expected quantile');
ylabel('Observed quantile');
line([0 20], [0 20], 'color', 'k');
```



Overall, the agreement between the expected and observed quantiles is good. Look at the right half of the plot. The deviation of the plot from the 45° line upward indicates that the data has tails heavier than a normal distribution. There are three possible outliers on the right: two observations from class 'setosa' and one observation from class 'virginica'.

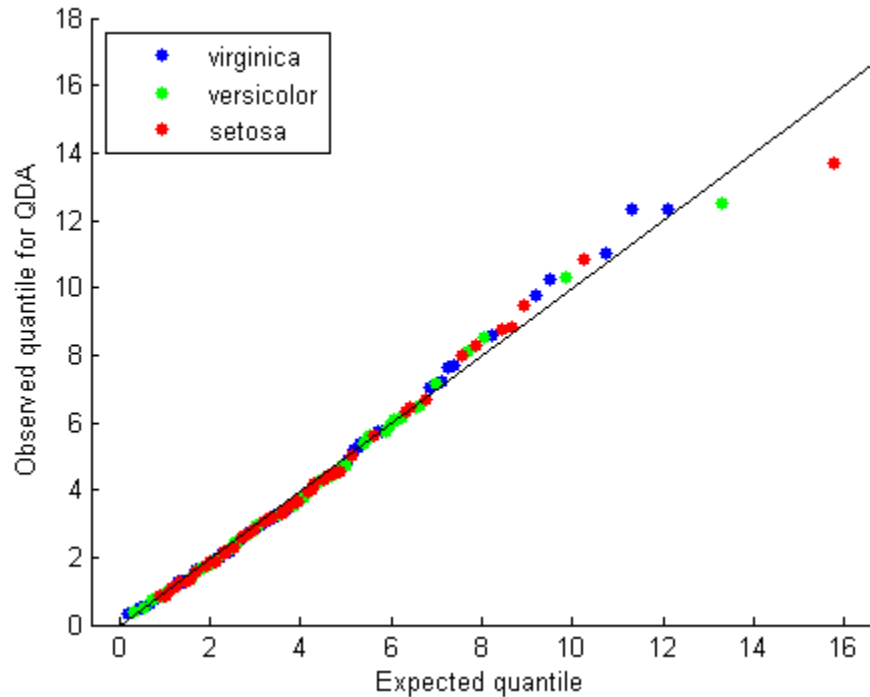
As shown in “Bartlett Test of Equal Covariance Matrices for Linear Discriminant Analysis” on page 12-29, the data does not match a single covariance matrix. Redo the calculations for a quadratic discriminant.

```
load fisheriris;
prednames = {'SepalLength', 'SepalWidth', ...
    'PetalLength', 'PetalWidth'};
Q = ClassificationDiscriminant.fit(meas, species, ...
    'PredictorNames', prednames, 'DiscrimType', 'quadratic');
Nclass = [50 50 50];
```

```

N = L.NObservations;
K = numel(L.ClassNames);
mahQ = mahal(Q,Q.X, 'ClassLabels',Q.Y);
expQ = chi2inv(((1:N)-0.5)/N,D);
[mahQ,sorted] = sort(mahQ);
figure;
gscatter(expQ,mahQ,Q.Y(sorted),'bgr',[],[],'off');
legend('virginica','versicolor','setosa','Location','NW');
xlabel('Expected quantile');
ylabel('Observed quantile for QDA');
line([0 20],[0 20],'color','k');

```



The Q-Q plot shows a better agreement between the observed and expected quantiles. There is only one outlier candidate, from class 'setosa'.

Mardia Kurtosis Test of Multivariate Normality

The Mardia kurtosis test (see Mardia [4]) is an alternative to examining a Q-Q plot. It gives a numeric approach to deciding if data matches a Gaussian mixture model.

In the Mardia kurtosis test you compute M , the mean of the fourth power of the Mahalanobis distance of the data from the class means. If the data is normally distributed with constant covariance matrix (and is thus suitable for linear discriminant analysis), M is asymptotically distributed as normal with mean $d(d + 2)$ and variance $8d(d + 2)/n$, where

- d is the number of predictors (number of dimensions in the data).
- n is the total number of observations.

The Mardia test is two sided: check whether M is close enough to $d(d + 2)$ with respect to a normal distribution of variance $8d(d + 2)/n$.

Example: Mardia Kurtosis Test for Linear and Quadratic Discriminants.

Check whether the Fisher iris data is approximately normally distributed for both linear and quadratic discriminant analysis. According to “Bartlett Test of Equal Covariance Matrices for Linear Discriminant Analysis” on page 12-29, the data is not normal for linear discriminant analysis (the covariance matrices are different). “Check Q-Q Plots for Linear and Quadratic Discriminants” on page 12-31 indicates that the data is well modeled by a Gaussian mixture model with different covariances per class. Check these conclusions with the Mardia kurtosis test:

```
load fisheriris;
prednames = {'SepalLength', 'SepalWidth', ...
            'PetalLength', 'PetalWidth'};
L = ClassificationDiscriminant.fit(meas, species, ...
    'PredictorNames', prednames);
mahL = mahal(L, L.X, 'ClassLabels', L.Y);
D = 4;
N = L.NObservations;
obsKurt = mean(mahL.^2);
expKurt = D*(D+2);
varKurt = 8*D*(D+2)/N;
[~, pval] = ztest(obsKurt, expKurt, sqrt(varKurt))
```



```
pval =  
    0.0208
```

The Mardia test indicates to reject the hypothesis that the data is normally distributed.

Continuing the example with quadratic discriminant analysis:

```
Q = ClassificationDiscriminant.fit(meas,species,...  
    'PredictorNames',prednames,'DiscrimType','quadratic');  
mahQ = mahal(Q,Q.X,'ClassLabels',Q.Y);  
obsKurt = mean(mahQ.^2);  
[~,pval] = ztest(obsKurt,expKurt,sqrt(varKurt))  
  
pval =  
    0.7230
```

Because `pval` is high, you conclude the data are consistent with the multivariate normal distribution.

Bibliography

[1] Box, G. E. P. *A General Distribution Theory for a Class of Likelihood Criteria*. *Biometrika* 36(3), pp. 317–346, 1949.

[2] Fisher, R. A. *The Use of Multiple Measurements in Taxonomic Problems*. *Annals of Eugenics*, Vol. 7, pp. 179–188, 1936. Available at <http://digital.library.adelaide.edu.au/dspace/handle/2440/15227>.

[3] Guo, Y., T. Hastie, and R. Tibshirani. *Regularized Discriminant Analysis and Its Application in Microarray*. *Biostatistics*, Vol. 8, No. 1, pp. 86–100, 2007.

[4] Mardia, K. V. *Measures of multivariate skewness and kurtosis with applications*. *Biometrika* 57 (3), pp. 519–530, 1970.

Naive Bayes Classification

The Naive Bayes classifier is designed for use when features are independent of one another within each class, but it appears to work well in practice even when that independence assumption is not valid. It classifies data in two steps:

- 1 Training step: Using the training samples, the method estimates the parameters of a probability distribution, assuming features are conditionally independent given the class.
- 2 Prediction step: For any unseen test sample, the method computes the posterior probability of that sample belonging to each class. The method then classifies the test sample according to the largest posterior probability.

The class-conditional independence assumption greatly simplifies the training step since you can estimate the one-dimensional class-conditional density for each feature individually. While the class-conditional independence between features is not true in general, research shows that this optimistic assumption works well in practice. This assumption of class independence allows the Naive Bayes classifier to better estimate the parameters required for accurate classification while using less training data than many other classifiers. This makes it particularly effective for datasets containing many predictors or features.

Supported Distributions

Naive Bayes classification is based on estimating $P(X|Y)$, the probability or probability density of features X given class Y . The Naive Bayes classification object `NaiveBayes` provides support for normal (Gaussian), kernel, multinomial, and multivariate multinomial distributions. It is possible to use different distributions for different features.

Normal (Gaussian) Distribution

The 'normal' distribution is appropriate for features that have normal distributions in each class. For each feature you model with a normal distribution, the Naive Bayes classifier estimates a separate normal

distribution for each class by computing the mean and standard deviation of the training data in that class.

Kernel Distribution

The 'kernel' distribution is appropriate for features that have a continuous distribution. It does not require a strong assumption such as a normal distribution and you can use it in cases where the distribution of a feature may be skewed or have multiple peaks or modes. It requires more computing time and more memory than the normal distribution. For each feature you model with a kernel distribution, the Naive Bayes classifier computes a separate kernel density estimate for each class based on the training data for that class. By default the kernel is the normal kernel, and the classifier selects a width automatically for each class and feature. It is possible to specify different kernels for each feature, and different widths for each feature or class.

Multinomial Distribution

The multinomial distribution (specify with the 'mn' keyword) is appropriate when all features represent counts of a set of words or tokens. This is sometimes called the "bag of words" model. For example, an email spam classifier might be based on features that count the number of occurrences of various tokens in an email. One feature might count the number of exclamation points, another might count the number of times the word "money" appears, and another might count the number of times the recipient's name appears. This is a Naive Bayes model under the further assumption that the total number of tokens (or the total document length) is independent of response class.

For the multinomial option, each feature represents the count of one token. The classifier counts the set of relative token probabilities separately for each class. The classifier defines the multinomial distribution for each row by the vector of probabilities for the corresponding class, and by N , the total token count for that row.

Classification is based on the relative frequencies of the tokens. For a row in which no token appears, N is 0 and no classification is possible. This classifier is not appropriate when the total number of tokens provides information about the response class.

Multivariate Multinomial Distribution

The multivariate multinomial distribution (specify with the 'mvmn' keyword) is appropriate for categorical features. For example, you could fit a feature describing the weather in categories such as rain/sun/snow/clouds using the multivariate multinomial model. The feature categories are sometimes called the feature levels, and differ from the class levels for the response variable.

For each feature you model with a multivariate multinomial distribution, the Naive Bayes classifier computes a separate set of probabilities for the set of feature levels for each class.

Performance Curves

In this section...

“Introduction to Performance Curves” on page 12-39

“What are ROC Curves?” on page 12-39

“Evaluate Classifier Performance Using `perfcurve`” on page 12-39

Introduction to Performance Curves

After a classification algorithm such as `NaiveBayes` or `TreeBagger` has trained on data, you may want to examine the performance of the algorithm on a specific test dataset. One common way of doing this would be to compute a gross measure of performance such as quadratic loss or accuracy, averaged over the entire test dataset.

What are ROC Curves?

You may want to inspect the classifier performance more closely, for example, by plotting a Receiver Operating Characteristic (ROC) curve. By definition, a ROC curve [1,2] shows true positive rate versus false positive rate (equivalently, sensitivity versus $1 - \text{specificity}$) for different thresholds of the classifier output. You can use it, for example, to find the threshold that maximizes the classification accuracy or to assess, in more broad terms, how the classifier performs in the regions of high sensitivity and high specificity.

Evaluate Classifier Performance Using `perfcurve`

`perfcurve` computes measures for a plot of classifier performance. You can use this utility to evaluate classifier performance on test data after you train the classifier. Various measures such as mean squared error, classification error, or exponential loss can summarize the predictive power of a classifier in a single number. However, a performance curve offers more information as it lets you explore the classifier performance across a range of thresholds on its output.

You can use `perfcurve` with any classifier or, more broadly, with any method that returns a numeric score for an instance of input data. By convention adopted here,

- A high score returned by a classifier for any given instance signifies that the instance is likely from the positive class.
- A low score signifies that the instance is likely from the negative classes.

For some classifiers, you can interpret the score as the posterior probability of observing an instance of the positive class at point X . An example of such a score is the fraction of positive observations in a leaf of a decision tree. In this case, scores fall into the range from 0 to 1 and scores from positive and negative classes add up to unity. Other methods can return scores ranging between minus and plus infinity, without any obvious mapping from the score to the posterior class probability.

`perfcurve` does not impose any requirements on the input score range. Because of this lack of normalization, you can use `perfcurve` to process scores returned by any classification, regression, or fit method. `perfcurve` does not make any assumptions about the nature of input scores or relationships between the scores for different classes. As an example, consider a problem with three classes, A, B, and C, and assume that the scores returned by some classifier for two instances are as follows:

	A	B	C
instance 1	0.4	0.5	0.1
instance 2	0.4	0.1	0.5

If you want to compute a performance curve for separation of classes A and B, with C ignored, you need to address the ambiguity in selecting A over B. You could opt to use the score ratio, $s(A)/s(B)$, or score difference, $s(A) - s(B)$; this choice could depend on the nature of these scores and their normalization. `perfcurve` always takes one score per instance. If you only supply scores for class A, `perfcurve` does not distinguish between observations 1 and 2. The performance curve in this case may not be optimal.

`perfcurve` is intended for use with classifiers that return scores, not those that return only predicted classes. As a counter-example, consider a decision tree that returns only hard classification labels, 0 or 1, for data with two classes. In this case, the performance curve reduces to a single point because classified instances can be split into positive and negative categories in one way only.

For input, `perfcurve` takes true class labels for some data and scores assigned by a classifier to these data. By default, this utility computes a Receiver Operating Characteristic (ROC) curve and returns values of 1-specificity, or false positive rate, for X and sensitivity, or true positive rate, for Y . You can choose other criteria for X and Y by selecting one out of several provided criteria or specifying an arbitrary criterion through an anonymous function. You can display the computed performance curve using `plot(X, Y)`.

`perfcurve` can compute values for various criteria to plot either on the x - or the y -axis. All such criteria are described by a 2-by-2 confusion matrix, a 2-by-2 cost matrix, and a 2-by-1 vector of scales applied to class counts.

The confusion matrix, C , is defined as

$$\begin{pmatrix} TP & FN \\ FP & TN \end{pmatrix}$$

where

- P stands for "positive".
- N stands for "negative".
- T stands for "true".
- F stands for "false".

For example, the first row of the confusion matrix defines how the classifier identifies instances of the positive class: $C(1, 1)$ is the count of correctly identified positive instances and $C(1, 2)$ is the count of positive instances misidentified as negative.

The cost matrix defines the cost of misclassification for each category:

$$\begin{pmatrix} Cost(P | P) & Cost(N | P) \\ Cost(P | N) & Cost(N | N) \end{pmatrix}$$

where $Cost(I | J)$ is the cost of assigning an instance of class J to class I . Usually $Cost(I | J) = 0$ for $I = J$. For flexibility, `perfcurve` allows you to specify nonzero costs for correct classification as well.

The two scales include prior information about class probabilities. `perfcurve` computes these scales by taking $\text{scale}(P) = \text{prior}(P) * N$ and $\text{scale}(N) = \text{prior}(N) * P$ and normalizing the sum $\text{scale}(P) + \text{scale}(N)$ to 1. $P = TP + FN$ and $N = TN + FP$ are the total instance counts in the positive and negative class, respectively. The function then applies the scales as multiplicative factors to the counts from the corresponding class: `perfcurve` multiplies counts from the positive class by $\text{scale}(P)$ and counts from the negative class by $\text{scale}(N)$. Consider, for example, computation of positive predictive value, $PPV = TP / (TP + FP)$. TP counts come from the positive class and FP counts come from the negative class. Therefore, you need to scale TP by $\text{scale}(P)$ and FP by $\text{scale}(N)$, and the modified formula for PPV with prior probabilities taken into account is now:

$$PPV = \frac{\text{scale}(P) * TP}{\text{scale}(P) * TP + \text{scale}(N) * FP}$$

If all scores in the data are above a certain threshold, `perfcurve` classifies all instances as 'positive'. This means that TP is the total number of instances in the positive class and FP is the total number of instances in the negative class. In this case, PPV is simply given by the prior:

$$PPV = \frac{\text{prior}(P)}{\text{prior}(P) + \text{prior}(N)}$$

The `perfcurve` function returns two vectors, X and Y, of performance measures. Each measure is some function of `confusion`, `cost`, and `scale` values. You can request specific measures by name or provide a function handle to compute a custom measure. The function you provide should take `confusion`, `cost`, and `scale` as its three inputs and return a vector of output values.

The criterion for X must be a monotone function of the positive classification count, or equivalently, threshold for the supplied scores. If `perfcurve` cannot perform a one-to-one mapping between values of the X criterion and score thresholds, it exits with an error message.

By default, `perfcurve` computes values of the X and Y criteria for all possible score thresholds. Alternatively, it can compute a reduced number of specific X values supplied as an input argument. In either case, for M requested values, `perfcurve` computes M+1 values for X and Y. The first value out of these M+1 values is special. `perfcurve` computes it by setting the TP instance count

to zero and setting TN to the total count in the negative class. This value corresponds to the 'reject all' threshold. On a standard ROC curve, this translates into an extra point placed at (0,0).

If there are NaN values among input scores, `perfcurve` can process them in either of two ways:

- It can discard rows with NaN scores.
- It can add them to false classification counts in the respective class.

That is, for any threshold, instances with NaN scores from the positive class are counted as false negative (FN), and instances with NaN scores from the negative class are counted as false positive (FP). In this case, the first value of X or Y is computed by setting TP to zero and setting TN to the total count minus the NaN count in the negative class. For illustration, consider an example with two rows in the positive and two rows in the negative class, each pair having a NaN score:

Class	Score
Negative	0.2
Negative	NaN
Positive	0.7
Positive	NaN

If you discard rows with NaN scores, then as the score cutoff varies, `perfcurve` computes performance measures as in the following table. For example, a cutoff of 0.5 corresponds to the middle row where rows 1 and 3 are classified correctly, and rows 2 and 4 are omitted.

TP	FN	FP	TN
0	1	0	1
1	0	0	1
1	0	1	0

If you add rows with NaN scores to the false category in their respective classes, `perfcurve` computes performance measures as in the following table. For example, a cutoff of 0.5 corresponds to the middle row where now rows

2 and 4 are counted as incorrectly classified. Notice that only the FN and FP columns differ between these two tables.

TP	FN	FP	TN
0	2	1	1
1	1	1	1
1	1	2	0

For data with three or more classes, `perfcurve` takes one positive class and a list of negative classes for input. The function computes the X and Y values using counts in the positive class to estimate TP and FN, and using counts in all negative classes to estimate TN and FP. `perfcurve` can optionally compute Y values for each negative class separately and, in addition to Y, return a matrix of size M-by-C, where M is the number of elements in X or Y and C is the number of negative classes. You can use this functionality to monitor components of the negative class contribution. For example, you can plot TP counts on the X-axis and FP counts on the Y-axis. In this case, the returned matrix shows how the FP component is split across negative classes.

You can also use `perfcurve` to estimate confidence intervals. `perfcurve` computes confidence bounds using either cross-validation or bootstrap. If you supply cell arrays for `labels` and `scores`, `perfcurve` uses cross-validation and treats elements in the cell arrays as cross-validation folds. If you set input parameter `NBoot` to a positive integer, `perfcurve` generates `nboot` bootstrap replicas to compute pointwise confidence bounds.

`perfcurve` estimates the confidence bounds using one of two methods:

- Vertical averaging (VA) — estimate confidence bounds on Y and T at fixed values of X. Use the `XVals` input parameter to use this method for computing confidence bounds.
- Threshold averaging (TA) — estimate confidence bounds for X and Y at fixed thresholds for the positive class score. Use the `TVals` input parameter to use this method for computing confidence bounds.

To use observation weights instead of observation counts, you can use the `'Weights'` parameter in your call to `perfcurve`. When you use this parameter, to compute X, Y and T or to compute confidence bounds by cross-validation, `perfcurve` uses your supplied observation weights instead of

observation counts. To compute confidence bounds by bootstrap, perfcurve samples N out of N with replacement using your weights as multinomial sampling probabilities.

Nonparametric Supervised Learning

- “Supervised Learning (Machine Learning) Workflow and Algorithms” on page 13-2
- “Classification Using Nearest Neighbors” on page 13-9
- “Classification Trees and Regression Trees” on page 13-30
- “Ensemble Methods” on page 13-54
- “Bibliography” on page 13-157

Supervised Learning (Machine Learning) Workflow and Algorithms

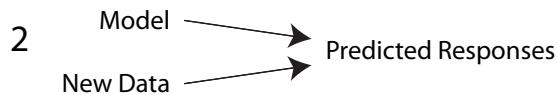
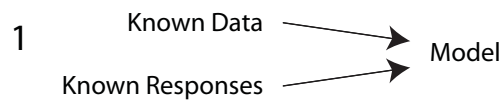
In this section...

“Steps in Supervised Learning (Machine Learning)” on page 13-2

“Characteristics of Algorithms” on page 13-7

Steps in Supervised Learning (Machine Learning)

Supervised learning (machine learning) takes a known set of input data and known responses to the data, and seeks to build a predictor model that generates reasonable predictions for the response to new data.



Suppose you want to predict if someone will have a heart attack within a year. You have a set of data on previous people, including age, weight, height, blood pressure, etc. You know if the previous people had heart attacks within a year of their data measurements. So the problem is combining all the existing data into a model that can predict whether a new person will have a heart attack within a year.

Supervised learning splits into two broad categories:

- Classification for responses that can have just a few known values, such as 'true' or 'false'. Classification algorithms apply to nominal, not ordinal response values.

- Regression for responses that are a real number, such as miles per gallon for a particular car.

You can have trouble deciding whether you have a classification problem or a regression problem. In that case, create a regression model first, because they are often more computationally efficient.

While there are many Statistics Toolbox algorithms for supervised learning, most use the same basic workflow for obtaining a predictor model. (Detailed instruction on the steps for ensemble learning is in “Framework for Ensemble Learning” on page 13-54.) The steps for supervised learning are:

- 1 “Prepare Data” on page 13-3
- 2 “Choose an Algorithm” on page 13-4
- 3 “Fit a Model” on page 13-4
- 4 “Choose a Validation Method” on page 13-5
- 5 “Examine Fit and Update Until Satisfied” on page 13-6
- 6 “Use Fitted Model for Predictions” on page 13-6

Prepare Data

All supervised learning methods start with an input data matrix, usually called X here. Each row of X represents one observation. Each column of X represents one variable, or predictor. Represent missing entries with NaN values in X . Statistics Toolbox supervised learning algorithms can handle NaN values, either by ignoring them or by ignoring any row with a NaN value.

You can use various data types for response data Y . Each element in Y represents the response to the corresponding row of X . Observations with missing Y data are ignored.

- For regression, Y must be a numeric vector with the same number of elements as the number of rows of X .
- For classification, Y can be any of these data types. This table also contains the method of including missing entries.

Data Type	Missing Entry
Numeric vector	NaN
Categorical vector	<undefined>
Character array	Row of spaces
Cell array of strings	' '
Logical vector	(Cannot represent)

Choose an Algorithm

There are tradeoffs between several characteristics of algorithms, such as:

- Speed of training
- Memory usage
- Predictive accuracy on new data
- Transparency or interpretability, meaning how easily you can understand the reasons an algorithm makes its predictions

Details of the algorithms appear in “Characteristics of Algorithms” on page 13-7. More detail about ensemble algorithms is in “Choose an Applicable Ensemble Method” on page 13-57.

Fit a Model

The fitting function you use depends on the algorithm you choose.

Algorithm	Fitting Function
Classification Trees	<code>ClassificationTree.fit</code>
Regression Trees	<code>RegressionTree.fit</code>
Discriminant Analysis (classification)	<code>ClassificationDiscriminant.fit</code>
<i>K</i> -Nearest Neighbors (classification)	<code>ClassificationKNN.fit</code>
Naive Bayes (classification)	<code>NaiveBayes.fit</code>

Algorithm	Fitting Function
Classification or Regression Ensembles	fitensemble
Classification or Regression Ensembles in Parallel	TreeBagger

Choose a Validation Method

The three main methods to examine the accuracy of the resulting fitted model are:

- Examine the resubstitution error. For examples, see:
 - “Example: Resubstitution Error of a Classification Tree” on page 13-37
 - “Example: Cross Validating a Regression Tree” on page 13-38
 - “Example: Test Ensemble Quality” on page 13-66
 - “Example: Resubstitution Error of a Discriminant Analysis Classifier” on page 12-17
- Examine the cross-validation error. For examples, see:
 - “Example: Cross Validating a Regression Tree” on page 13-38
 - “Example: Test Ensemble Quality” on page 13-66
 - “Classification with Many Categorical Levels” on page 13-83
 - “Example: Cross Validating a Discriminant Analysis Classifier” on page 12-18
- Examine the out-of-bag error for bagged decision trees. For examples, see:
 - “Example: Test Ensemble Quality” on page 13-66
 - “Workflow Example: Regression of Insurance Risk Rating for Car Imports with TreeBagger” on page 13-120
 - “Workflow Example: Classifying Radar Returns for Ionosphere Data with TreeBagger” on page 13-129

Examine Fit and Update Until Satisfied

After validating the model, you might want to change it for better accuracy, better speed, or to use less memory.

- Change fitting parameters to try to get a more accurate model. For examples, see:
 - “Tuning RobustBoost” on page 13-110
 - “Example: Unequal Classification Costs” on page 13-78
 - “Improve a Discriminant Analysis Classifier” on page 12-14
- Change fitting parameters to try to get a smaller model. This sometimes gives a model with more accuracy. For examples, see:
 - “Example: Selecting Appropriate Tree Depth” on page 13-39
 - “Example: Pruning a Classification Tree” on page 13-42
 - “Surrogate Splits” on page 13-88
 - “Example: Regularizing a Regression Ensemble” on page 13-100
 - “Workflow Example: Regression of Insurance Risk Rating for Car Imports with TreeBagger” on page 13-120
 - “Workflow Example: Classifying Radar Returns for Ionosphere Data with TreeBagger” on page 13-129
- Try a different algorithm. For applicable choices, see:
 - “Characteristics of Algorithms” on page 13-7
 - “Choose an Applicable Ensemble Method” on page 13-57

When satisfied with a model of some types, you can trim it using the appropriate `compact` method (`compact` for classification trees, `compact` for classification ensembles, `compact` for regression trees, `compact` for regression ensembles, `compact` for discriminant analysis). `compact` removes training data and pruning information, so the model uses less memory.

Use Fitted Model for Predictions

To predict classification or regression response for most fitted models, use the `predict` method:

```
Ypredicted = predict(obj,Xnew)
```

- obj is the fitted model object.
- Xnew is the new input data.
- Ypredicted is the predicted response, either classification or regression.

For classtree, use the eval method instead of predict.

Characteristics of Algorithms

This table shows typical characteristics of the various supervised learning algorithms. The characteristics in any particular case can vary from the listed ones. Use the table as a guide for your initial choice of algorithms, but be aware that the table can be inaccurate for some problems.

Characteristics of Supervised Learning Algorithms

Algorithm	Predictive Accuracy	Fitting Speed	Prediction Speed	Memory Usage	Easy to Interpret	Handles Categorical Predictors
Trees	Low	Fast	Fast	Low	Yes	Yes
SVM in Bioinformatics Toolbox™	High	Medium	*	*	*	No
Naive Bayes	Low	**	**	**	Yes	Yes
Nearest Neighbor	***	Fast***	Medium	High	No	Yes***
Discriminant Analysis	****	Fast	Fast	Low	Yes	No
Ensembles	See “Suggestions for Choosing an Appropriate Ensemble Algorithm” on page 13-59 and “General Characteristics of Ensemble Algorithms” on page 13-60					

* — SVM prediction speed and memory usage are good if there are few support vectors, but can be poor if there are many support vectors. When you use a kernel function, it can be difficult to interpret how SVM classifies data,

though the default linear scheme is easy to interpret. SVM is available if you have a Bioinformatics Toolbox license.

** — Naive Bayes speed and memory usage are good for simple distributions, but can be poor for kernel distributions and large data sets.

*** — Nearest Neighbor usually has good predictions in low dimensions, but can have poor predictions in high dimensions. For linear search, Nearest Neighbor does not perform any fitting. For k d-trees, Nearest Neighbor does perform fitting. Nearest Neighbor can have either continuous or categorical predictors, but not both.

**** — Discriminant Analysis is accurate when the modeling assumptions are satisfied (multivariate normal by class). Otherwise, the predictive accuracy varies.

Classification Using Nearest Neighbors

In this section...

“Pairwise Distance” on page 13-9

“ k -Nearest Neighbor Search and Radius Search” on page 13-12

“ K -Nearest Neighbor Classification for Supervised Learning” on page 13-25

“Construct a KNN Classifier” on page 13-25

“Examine the Quality of a KNN Classifier” on page 13-26

“Predict Classification Based on a KNN Classifier” on page 13-27

“Modify a KNN Classifier” on page 13-27

Pairwise Distance

Categorizing query points based on their distance to points in a training dataset can be a simple yet effective way of classifying new points. You can use various metrics to determine the distance, described next. Use `pdist2` to find the distance between a set of data and query points.

Distance Metrics

Given an $m \times n$ data matrix X , which is treated as $m \times (1 \text{-by-} n)$ row vectors $x_1, x_2, \dots, x_{m \times}$, and $m \times n$ data matrix Y , which is treated as $m \times (1 \text{-by-} n)$ row vectors $y_1, y_2, \dots, y_{m \times}$, the various distances between the vector x_s and y_t are defined as follows:

- Euclidean distance

$$d_{st}^2 = (x_s - y_t)(x_s - y_t)'$$

The Euclidean distance is a special case of the Minkowski metric, where $p = 2$.

- Standardized Euclidean distance

$$d_{st}^2 = (x_s - y_t)V^{-1}(x_s - y_t)'$$

where V is the n -by- n diagonal matrix whose j th diagonal element is $S(j)^2$, where S is the vector containing the inverse weights.

- Mahalanobis distance

$$d_{st}^2 = (x_s - y_t)C^{-1}(x_s - y_t)'$$

where C is the covariance matrix.

- City block metric

$$d_{st} = \sum_{j=1}^n |x_{sj} - y_{tj}|$$

The city block distance is a special case of the Minkowski metric, where $p = 1$.

- Minkowski metric

$$d_{st} = \sqrt[p]{\sum_{j=1}^n |x_{sj} - y_{tj}|^p}$$

For the special case of $p = 1$, the Minkowski metric gives the city block metric, for the special case of $p = 2$, the Minkowski metric gives the Euclidean distance, and for the special case of $p = \infty$, the Minkowski metric gives the Chebychev distance.

- Chebychev distance

$$d_{st} = \max_j \{|x_{sj} - y_{tj}|\}$$

The Chebychev distance is a special case of the Minkowski metric, where $p = \infty$.

- Cosine distance

$$d_{st} = \left(1 - \frac{x_s y_t'}{\sqrt{(x_s x_s')(y_t y_t')}} \right)$$

- Correlation distance

$$d_{st} = 1 - \frac{(x_s - \bar{x}_s)(y_t - \bar{y}_t)'}{\sqrt{(x_s - \bar{x}_s)(x_s - \bar{x}_s)' (y_t - \bar{y}_t)(y_t - \bar{y}_t)'}}$$

where

$$\bar{x}_s = \frac{1}{n} \sum_j x_{sj}$$

and

$$\bar{y}_t = \frac{1}{n} \sum_j y_{tj}$$

- Hamming distance

$$d_{st} = (\#(x_{sj} \neq y_{tj}) / n)$$

- Jaccard distance

$$d_{st} = \frac{\#[(x_{sj} \neq y_{tj}) \cap ((x_{sj} \neq 0) \cup (y_{tj} \neq 0))]}{\#[(x_{sj} \neq 0) \cup (y_{tj} \neq 0)]}$$

- Spearman distance

$$d_{st} = 1 - \frac{(r_s - \bar{r}_s)(r_t - \bar{r}_t)'}{\sqrt{(r_s - \bar{r}_s)(r_s - \bar{r}_s)' (r_t - \bar{r}_t)(r_t - \bar{r}_t)'}}$$

where

- r_{sj} is the rank of x_{sj} taken over $x_{1j}, x_{2j}, \dots, x_{mj}$, as computed by tiedrank.
- r_{tj} is the rank of y_{tj} taken over $y_{1j}, y_{2j}, \dots, y_{mj}$, as computed by tiedrank.
- r_s and r_t are the coordinate-wise rank vectors of x_s and y_t , i.e., $r_s = (r_{s1}, r_{s2}, \dots, r_{sn})$ and $r_t = (r_{t1}, r_{t2}, \dots, r_{tn})$.

$$\bar{r}_s = \frac{1}{n} \sum_j r_{sj} = \frac{(n+1)}{2}.$$

$$\bar{r}_t = \frac{1}{n} \sum_j r_{tj} = \frac{(n+1)}{2}.$$

***k*-Nearest Neighbor Search and Radius Search**

Given a set X of n points and a distance function, k -nearest neighbor (k NN) search lets you find the k closest points in X to a query point or set of points Y . The k NN search technique and k NN-based algorithms are widely used as benchmark learning rules. The relative simplicity of the k NN search technique makes it easy to compare the results from other classification techniques to k NN results. The technique has been used in various areas such as:

- bioinformatics
- image processing and data compression
- document retrieval
- computer vision
- multimedia database
- marketing data analysis

You can use k NN search for other machine learning algorithms, such as:

- k NN classification
- local weighted regression
- missing data imputation and interpolation
- density estimation

You can also use k NN search with many distance-based learning functions, such as K-means clustering.

In contrast, for a positive real value r , `rangesearch` finds all points in X that are within a distance r of each point in Y . This fixed-radius search is closely

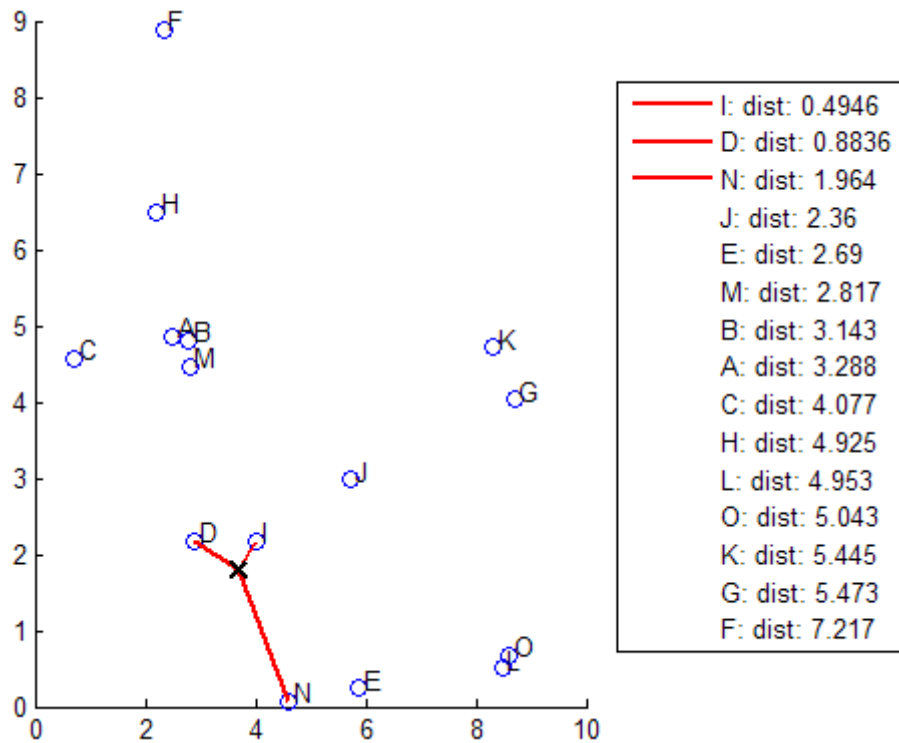
related to k NN search, as it supports the same distance metrics and search classes, and uses the same search algorithms.

***k*-Nearest Neighbor Search Using Exhaustive Search**

When your input data meets any of the following criteria, `knnsearch` uses the exhaustive search method by default to find the k -nearest neighbors:

- The number of columns of X is more than 10.
- X is sparse.
- The distance measure is either:
 - 'seuclidean'
 - 'mahalanobis'
 - 'cosine'
 - 'correlation'
 - 'spearman'
 - 'hamming'
 - 'jaccard'
 - A custom distance function

`knnsearch` also uses the exhaustive search method if your search object is an `ExhaustiveSearcher` object. The exhaustive search method finds the distance from each query point to every point in X , ranks them in ascending order, and returns the k points with the smallest distances. For example, this diagram shows the $k = 3$ nearest neighbors.



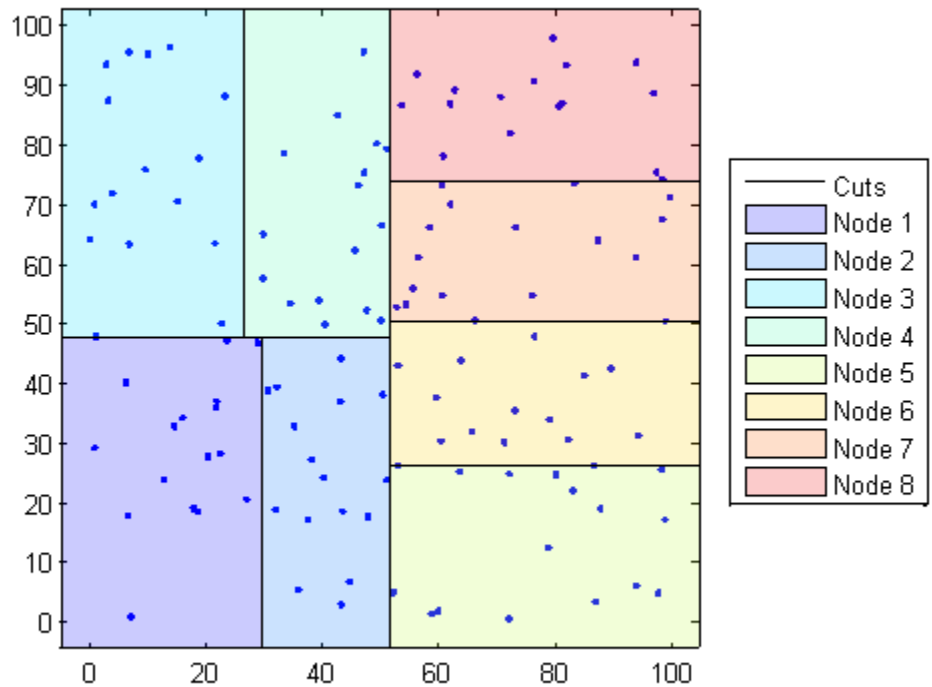
***k*-Nearest Neighbor Search Using a *kd*-Tree**

When your input data meets all of the following criteria, `knnsearch` creates a *kd*-tree by default to find the *k*-nearest neighbors:

- The number of columns of *X* is less than 10.
- *X* is not sparse.
- The distance measure is either:
 - 'euclidean' (default)
 - 'cityblock'
 - 'minkowski'
 - 'chebychev'

`knnsearch` also uses a *kd*-tree if your search object is a `KDTreeSearcher` object.

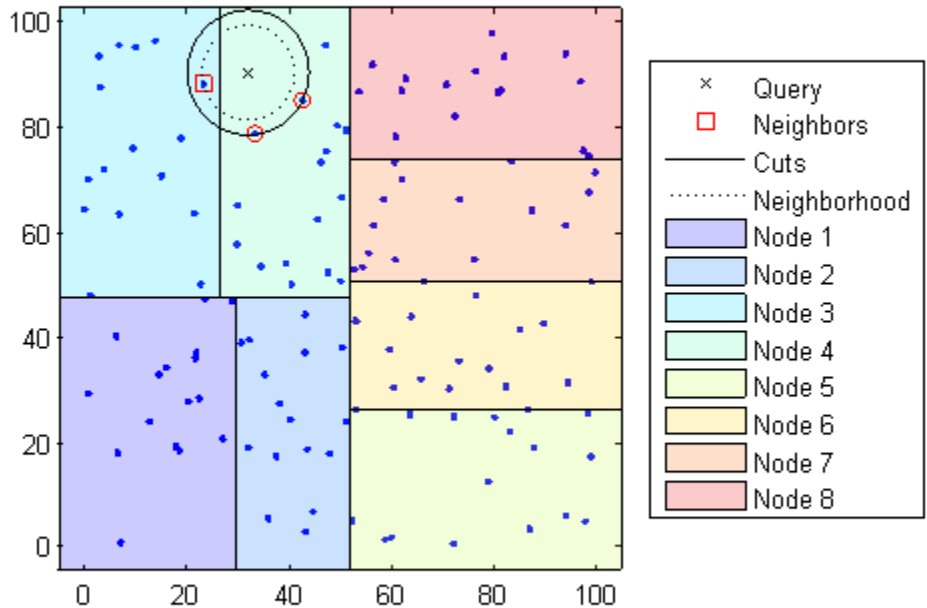
kd-trees divide your data into nodes with at most `BucketSize` (default is 50) points per node, based on coordinates (as opposed to categories). The following diagrams illustrate this concept using patch objects to color code the different “buckets.”



When you want to find the *k*-nearest neighbors to a given query point, `knnsearch` does the following:

- 1 Determines the node to which the query point belongs. In the following example, the query point (32,90) belongs to Node 4.

- 2** Finds the closest k points within that node and its distance to the query point. In the following example, the points in red circles are equidistant from the query point, and are the closest points to the query point within Node 4.
- 3** Chooses all other nodes having any area that is within the same distance, in any direction, from the query point to the k th closest point. In this example, only Node 3 overlaps the solid black circle centered at the query point with radius equal to the distance to the closest points within Node 4.
- 4** Searches nodes within that range for any points closer to the query point. In the following example, the point in a red square is slightly closer to the query point than those within Node 4.



Using a *kd*-tree for large datasets with fewer than 10 dimensions (columns) can be much more efficient than using the exhaustive search method, as `knnsearch` needs to calculate only a subset of the distances. To maximize the efficiency of *kd*-trees, use a `KDTreeSearcher` object.

What Are Search Objects?

Basically, objects are a convenient way of storing information. Classes of related objects (for example, all search objects) have the same properties with values and types relevant to a specified search method. In addition to storing information within objects, you can perform certain actions (called *methods*) on objects.

All search objects have a `knnsearch` method specific to that class. This lets you efficiently perform a *k*-nearest neighbors search on your object for that specific object type. In addition, there is a generic `knnsearch` function that searches without creating or using an object.

To determine which type of object and search method is best for your data, consider the following:

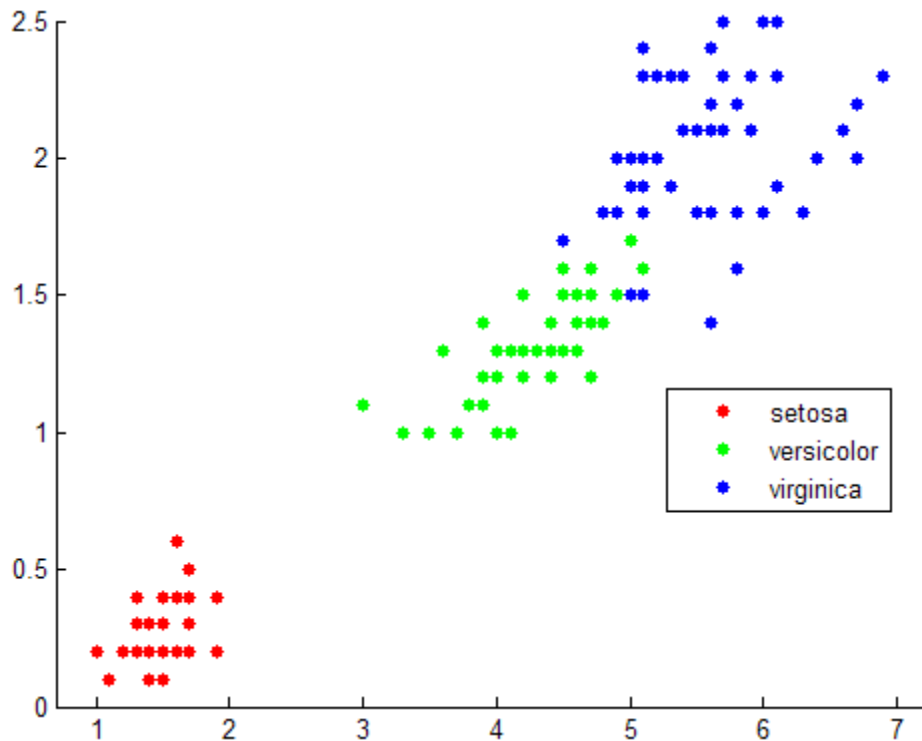
- Does your data have many columns, say more than 10? The `ExhaustiveSearcher` object may perform better.
- Is your data sparse? Use the `ExhaustiveSearcher` object.
- Do you want to use one of these distance measures to find the nearest neighbors? Use the `ExhaustiveSearcher` object.
 - `'seuclidean'`
 - `'mahalanobis'`
 - `'cosine'`
 - `'correlation'`
 - `'spearman'`
 - `'hamming'`
 - `'jaccard'`
 - A custom distance function

- Is your dataset huge (but with fewer than 10 columns)? Use the `KDTreeSearcher` object.
- Are you searching for the nearest neighbors for a large number of query points? Use the `KDTreeSearcher` object.

Example: Classifying Query Data Using `knnsearch`

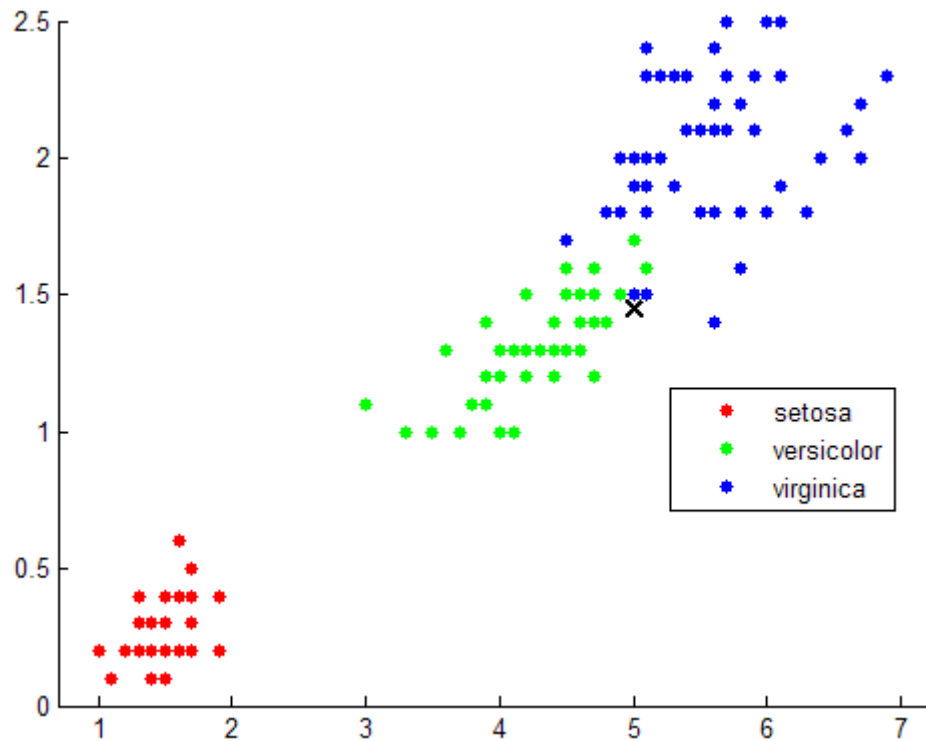
- 1 Classify a new point based on the last two columns of the Fisher iris data. Using only the last two columns makes it easier to plot:

```
load fisheriris
x = meas(:,3:4);
gscatter(x(:,1),x(:,2),species)
set(legend,'location','best')
```

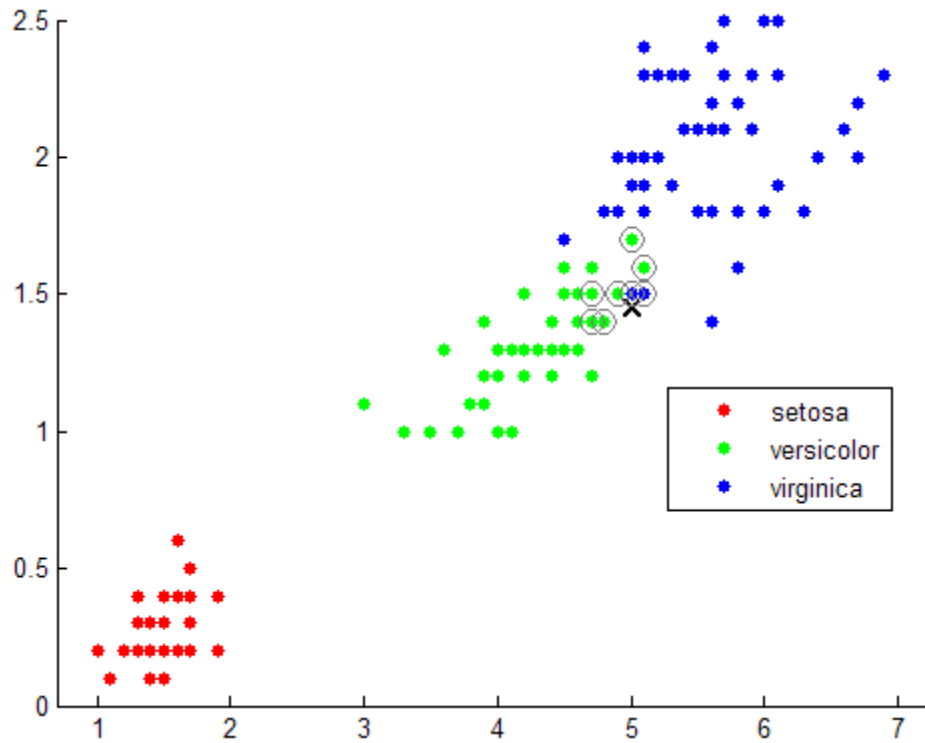


2 Plot the new point:

```
newpoint = [5 1.45];
line(newpoint(1),newpoint(2),'marker','x','color','k',...
      'markersize',10,'linewidth',2)
```

**3** Find the 10 sample points closest to the new point:

```
[n,d] = knnsearch(x,newpoint,'k',10)
line(x(n,1),x(n,2),'color',[.5 .5 .5],'marker','o',...
      'linestyle','none','markersize',10)
```



4 It appears that knnsearch has found only the nearest eight neighbors. In fact, this particular dataset contains duplicate values:

`x(n, :)`

`ans =`

```

5.0000    1.5000
4.9000    1.5000
4.9000    1.5000
5.1000    1.5000
5.1000    1.6000
4.8000    1.4000
5.0000    1.7000
4.7000    1.4000
4.7000    1.4000
    
```


4.7000 1.5000

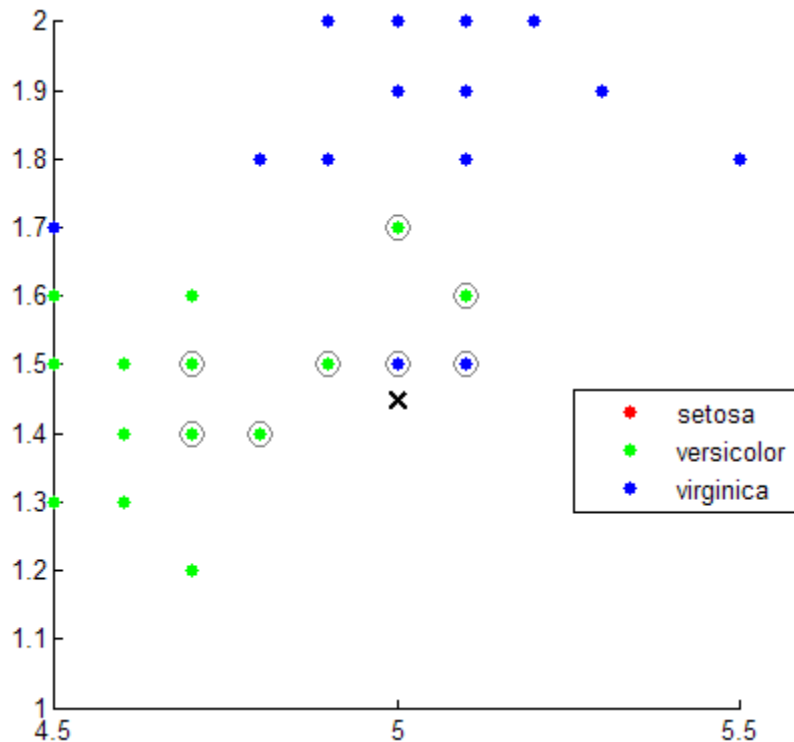
- 5** To make duplicate values visible on the plot, use the following code:

```
% jitter to make repeated points visible
xj = x + .05*(rand(150,2) - .5);
gscatter(xj(:,1),xj(:,2),species)
```

The jittered points do not affect any analysis of the data, only the visualization. This example does not jitter the points.

- 6** Make the axes equal so the calculated distances correspond to the apparent distances on the plot axis equal and zoom in to see the neighbors better:

```
set(gca,'xlim',[4.5 5.5],'ylim',[1 2]); axis square
```



- 7** Find the species of the 10 neighbors:

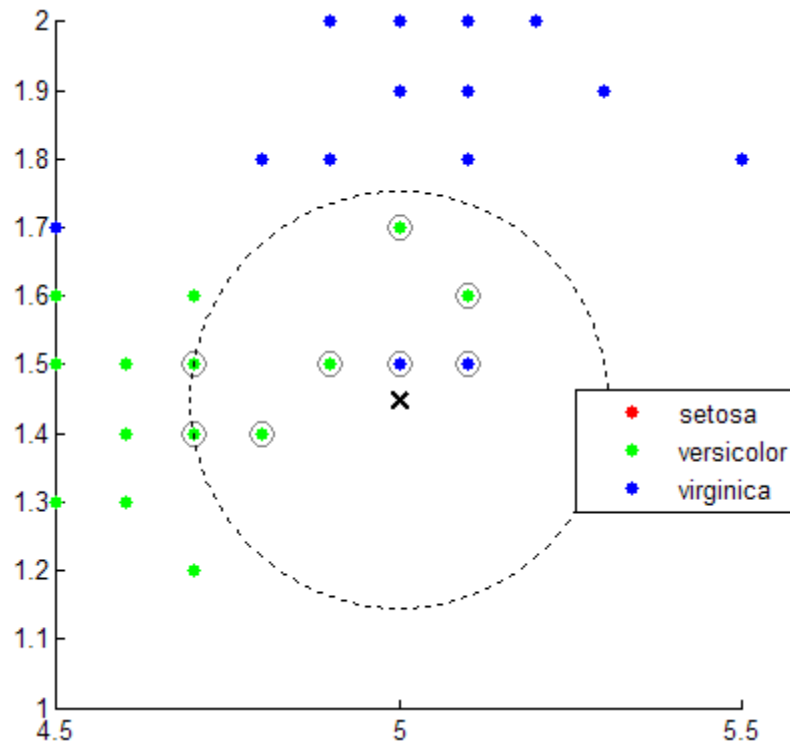
```
tabulate(species(n))
```

Value	Count	Percent
virginica	2	20.00%
versicolor	8	80.00%

Using a rule based on the majority vote of the 10 nearest neighbors, you can classify this new point as a versicolor.

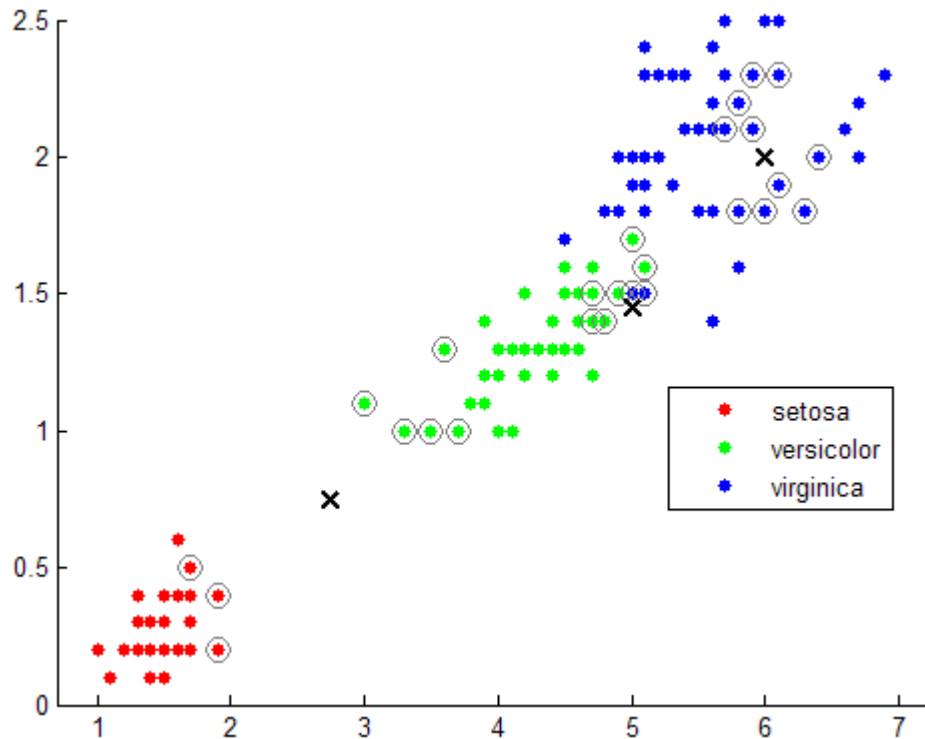
- 8** Visually identify the neighbors by drawing a circle around the group of them:

```
% Define the center and diameter of a circle, based on the  
% location of the new point:  
ctr = newpoint - d(end);  
diameter = 2*d(end);  
% Draw a circle around the 10 nearest neighbors:  
h = rectangle('position',[ctr,diameter,diameter],...  
    'curvature',[1 1]);  
set(h,'linestyle',':')
```



- 9 Using the same dataset, find the 10 nearest neighbors to three new points:

```
figure
newpoint2 = [5 1.45;6 2;2.75 .75];
gscatter(x(:,1),x(:,2),species)
legend('location','best')
[n2,d2] = knnsearch(x,newpoint2,'k',10);
line(x(n2,1),x(n2,2),'color',[.5 .5 .5],'marker','o',...
     'linestyle','none','markersize',10)
line(newpoint2(:,1),newpoint2(:,2),'marker','x','color','k',...
     'markersize',10,'linewidth',2,'linestyle','none')
```



10 Find the species of the 10 nearest neighbors for each new point:

```
tabulate(species(n2(1, :)))
  Value  Count  Percent
  virginica      2    20.00%
  versicolor     8    80.00%
```

```
tabulate(species(n2(2, :)))
  Value  Count  Percent
  virginica    10   100.00%
```

```
tabulate(species(n2(3, :)))
  Value  Count  Percent
  versicolor    7    70.00%
  setosa        3    30.00%
```

For more examples using `knnsearch` methods and function, see the individual reference pages.

K-Nearest Neighbor Classification for Supervised Learning

The `ClassificationKNN` class lets you:

- “Construct a KNN Classifier” on page 13-25
- “Examine the Quality of a KNN Classifier” on page 13-26
- “Predict Classification Based on a KNN Classifier” on page 13-27
- “Modify a KNN Classifier” on page 13-27

Work with the classifier as you would with `ClassificationTree` or `ClassificationDiscriminant`. In particular, prepare your data for classification according to the procedure in “Steps in Supervised Learning (Machine Learning)” on page 13-2. Then construct the classifier using `ClassificationKNN.fit`.

Construct a KNN Classifier

This example shows how to construct a k -nearest neighbor classifier for the Fisher iris data.

Load the Fisher iris data.

```
load fisheriris
X = meas; % use all data for fitting
Y = species; % response data
```

Construct the classifier using `ClassificationKNN.fit`.

```
mdl = ClassificationKNN.fit(X,Y)
```

```
mdl =
```

```
ClassificationKNN:
  PredictorNames: {'x1' 'x2' 'x3' 'x4'}
  ResponseName: 'Y'
```

```
      ClassNames: {'setosa' 'versicolor' 'virginica'}  
ScoreTransform: 'none'  
NObservations: 150  
      Distance: 'euclidean'  
NumNeighbors: 1
```

A default k -nearest neighbor classifier uses just the single nearest neighbor. Often, a classifier is more robust with more neighbors than that. Change the neighborhood size of `mdl` to 4, meaning `mdl` classifies using the four nearest neighbors:

```
mdl.NumNeighbors = 4;
```

Examine the Quality of a KNN Classifier

This example shows how to examine the quality of a k -nearest neighbor classifier using resubstitution and cross validation.

Construct a KNN classifier for the Fisher iris data as in “Construct a KNN Classifier” on page 13-25.

```
load fisheriris  
X = meas; % use all data for fitting  
Y = species; % response data  
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',4);
```

Examine the resubstitution loss, which, by default, is the fraction of misclassifications from the predictions of `mdl`. (For nondefault cost, weights, or priors, see `ClassificationKNN.loss`.)

```
rloss = resubLoss(mdl)
```

```
rloss =  
  
    0.0400
```

The classifier predicts incorrectly for 4% of the training data.

Construct a cross-validated classifier from the model.

```
cvmdl = crossval(mdl);
```

Examine the cross-validation loss, which is the average loss of each cross-validation model when predicting on data that is not used for training.

```
kloss = kfoldLoss(cvmdl)

kloss =

    0.0600
```

The cross-validated classification accuracy resembles the resubstitution accuracy. Therefore, you can expect mdl to misclassify approximately 5% of new data, assuming that the new data has about the same distribution as the training data.

Predict Classification Based on a KNN Classifier

This example shows how to predict classification for a k -nearest neighbor classifier.

Construct a default KNN classifier for the Fisher iris data as in “Construct a KNN Classifier” on page 13-25.

```
load fisheriris
X = meas; % use all data for fitting
Y = species; % response data
mdl = ClassificationKNN.fit(X,Y);
```

Predict the classification of an average flower.

```
flwr = mean(X); % an average flower
flwrClass = predict(mdl,flwr)

flwrClass =

    'versicolor'
```

Modify a KNN Classifier

This example shows how to modify a k -nearest neighbor classifier.

Construct a default KNN classifier for the Fisher iris data as in “Construct a KNN Classifier” on page 13-25.

```
load fisheriris
X = meas; % use all data for fitting
Y = species; % response data
mdl = ClassificationKNN.fit(X,Y);
```

Modify the model to use the three nearest neighbors, rather than the default one nearest neighbor.

```
mdl.NumNeighbors = 3;
```

Compare the resubstitution predictions and cross-validation loss with the new number of neighbors.

```
rloss = resubLoss(mdl)
```

```
rloss =
```

```
0.0400
```

```
cvmdl = crossval(mdl,'kfold',5);
kloss = kfoldLoss(cvmdl)
```

```
kloss =
```

```
0.0333
```

The model with three neighbors has lower cross-validated loss than a model with four neighbors (see “Examine the Quality of a KNN Classifier” on page 13-26).

Modify the model to use cosine distance instead of the default, and examine the loss. To use cosine distance, you must recreate the model using the exhaustive search method.

```
cmdl = ClassificationKNN.fit(X,Y,'NSMethod','exhaustive',...
    'Distance','cosine');
```

```
cmdl.NumNeighbors = 3;
closs = resubLoss(cmdl)
```

```
closs =
```

```
0.0200
```


The classifier now has lower resubstitution error than before.

Check the quality of a cross-validated version of the new model.

```
cvcmdl = crossval(cmdl);  
kcloss = kfoldLoss(cvcmdl)
```

```
kcloss =
```

```
    0.0333
```

The cross-validated loss is the same as before. The lesson is that improving the resubstitution error does not necessarily produce a model with better predictions.

Classification Trees and Regression Trees

In this section...

“What Are Classification Trees and Regression Trees?” on page 13-30

“Creating a Classification Tree” on page 13-31

“Creating a Regression Tree” on page 13-31

“Viewing a Tree” on page 13-32

“How the Fit Methods Create Trees” on page 13-34

“Predicting Responses With Classification and Regression Trees” on page 13-36

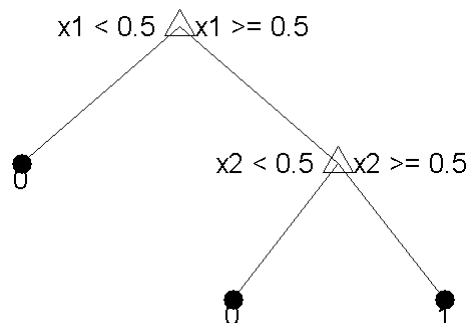
“Improving Classification Trees and Regression Trees” on page 13-37

“Alternative: classregtree” on page 13-46

What Are Classification Trees and Regression Trees?

Classification trees and regression trees predict responses to data. To predict a response, follow the decisions in the tree from the root (beginning) node down to a leaf node. The leaf node contains the response. Classification trees give responses that are nominal, such as 'true' or 'false'. Regression trees give numeric responses.

Statistics Toolbox trees are binary. Each step in a prediction involves checking the value of one predictor (variable). For example, here is a simple classification tree:



This tree predicts classifications based on two predictors, x_1 and x_2 . To predict, start at the top node, represented by a triangle (Δ). The first decision is whether x_1 is smaller than 0.5. If so, follow the left branch, and see that the tree classifies the data as type 0.

If, however, x_1 exceeds 0.5, then follow the right branch to the lower-right triangle node. Here the tree asks if x_2 is smaller than 0.5. If so, then follow the left branch to see that the tree classifies the data as type 0. If not, then follow the right branch to see that the that the tree classifies the data as type 1.

To learn how to prepare your data for classification or regression using decision trees, see “Steps in Supervised Learning (Machine Learning)” on page 13-2.

Creating a Classification Tree

To create a classification tree for the ionosphere data:

```
load ionosphere % contains X and Y variables
ctree = ClassificationTree.fit(X,Y)
```

```
ctree =
```

```
ClassificationTree:
    PredictorNames: {1x34 cell}
    CategoricalPredictors: []
    ResponseName: 'Y'
    ClassNames: {'b' 'g'}
    ScoreTransform: 'none'
    NObservations: 351
```

Creating a Regression Tree

To create a regression tree for the carsmall data based on the Horsepower and Weight vectors for data, and MPG vector for response:

```
load carsmall % contains Horsepower, Weight, MPG
X = [Horsepower Weight];
rtree = RegressionTree.fit(X,MPG)
```

```
rtree =  
  
RegressionTree:  
  PredictorNames: {'x1' 'x2'}  
  CategoricalPredictors: []  
  ResponseName: 'Y'  
  ResponseTransform: 'none'  
  NObservations: 94
```

Viewing a Tree

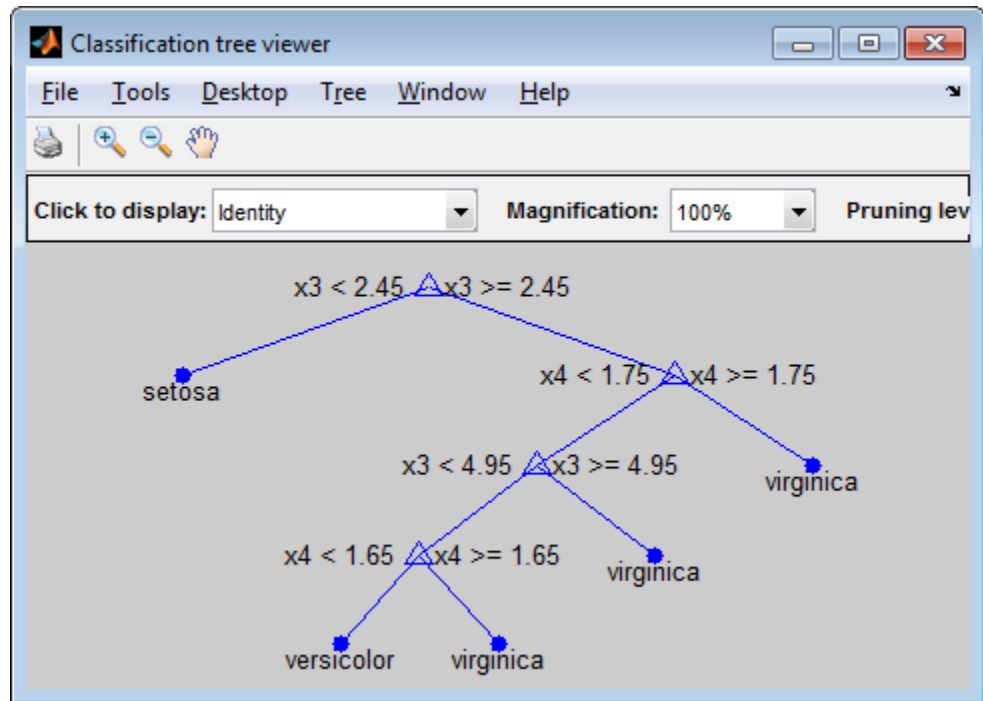
There are two ways to view a tree:

- `view(tree)` returns a text description of the tree.
- `view(tree, 'mode', 'graph')` returns a graphic description of the tree.

“Creating a Classification Tree” on page 13-31 has the following two views:

```
load fisheriris  
ctree = ClassificationTree.fit(meas, species);  
view(ctree)
```

```
Decision tree for classification  
1  if x3<2.45 then node 2 elseif x3>=2.45 then node 3 else setosa  
2  class = setosa  
3  if x4<1.75 then node 4 elseif x4>=1.75 then node 5 else versicolor  
4  if x3<4.95 then node 6 elseif x3>=4.95 then node 7 else versicolor  
5  class = virginica  
6  if x4<1.65 then node 8 elseif x4>=1.65 then node 9 else versicolor  
7  class = virginica  
8  class = versicolor  
9  class = virginica  
  
view(ctree, 'mode', 'graph')
```



Similarly, “Creating a Regression Tree” on page 13-31 has the following two views:

```
load carsmall % contains Horsepower, Weight, MPG
X = [Horsepower Weight];
rtree = RegressionTree.fit(X,MPG,'MinParent',30);
view(rtree)
```

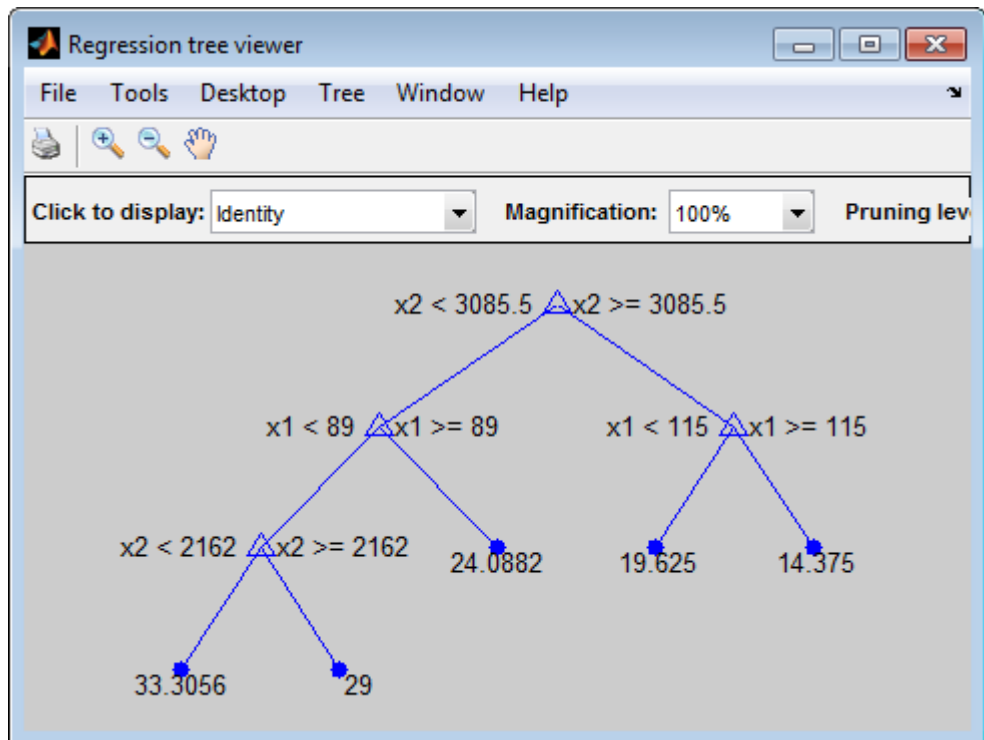
Decision tree for regression

```
1 if x2<3085.5 then node 2 elseif x2>=3085.5 then node 3 else 23.7181
2 if x1<89 then node 4 elseif x1>=89 then node 5 else 28.7931
3 if x1<115 then node 6 elseif x1>=115 then node 7 else 15.5417
4 if x2<2162 then node 8 elseif x2>=2162 then node 9 else 30.9375
5 fit = 24.0882
6 fit = 19.625
7 fit = 14.375
```

```
8 fit = 33.3056
```

```
9 fit = 29
```

```
view(rtree, 'mode', 'graph')
```



How the Fit Methods Create Trees

The `ClassificationTree.fit` and `RegressionTree.fit` methods perform the following steps to create decision trees:

- 1 Start with all input data, and examine all possible binary splits on every predictor.
- 2 Select a split with best optimization criterion.

- If the split leads to a child node having too few observations (less than the `MinLeaf` parameter), select a split with the best optimization criterion subject to the `MinLeaf` constraint.

3 Impose the split.

4 Repeat recursively for the two child nodes.

The explanation requires two more items: description of the optimization criterion, and stopping rule.

Stopping rule: Stop splitting when any of the following hold:

- The node is *pure*.
 - For classification, a node is pure if it contains only observations of one class.
 - For regression, a node is pure if the mean squared error (MSE) for the observed response in this node drops below the MSE for the observed response in the entire data multiplied by the tolerance on quadratic error per node (`qetoler` parameter).
- There are fewer than `MinParent` observations in this node.
- Any split imposed on this node would produce children with fewer than `MinLeaf` observations.

Optimization criterion:

- Regression: mean-squared error (MSE). Choose a split to minimize the MSE of predictions compared to the training data.
- Classification: One of three measures, depending on the setting of the `SplitCriterion` name-value pair:
 - `'gdi'` (Gini's diversity index, the default)
 - `'twoing'`
 - `'deviance'`

For details, see `ClassificationTree` “Definitions” on page 20-240.

For a continuous predictor, a tree can split halfway between any two adjacent unique values found for this predictor. For a categorical predictor with L levels, a classification tree needs to consider $2^{L-1}-1$ splits. To obtain this formula, observe that you can assign L distinct values to the left and right nodes in 2^L ways. Two out of these 2^L configurations would leave either left or right node empty, and therefore should be discarded. Now divide by 2 because left and right can be swapped. A classification tree can thus process only categorical predictors with a moderate number of levels. A regression tree employs a computational shortcut: it sorts the levels by the observed mean response, and considers only the $L-1$ splits between the sorted levels.

Predicting Responses With Classification and Regression Trees

After creating a tree, you can easily predict responses for new data. Suppose X_{new} is new data that has the same number of columns as the original data X . To predict the classification or regression based on the tree and the new data, enter

```
Ynew = predict(tree,Xnew);
```

For each row of data in X_{new} , `predict` runs through the decisions in `tree` and gives the resulting prediction in the corresponding element of Y_{new} . For more information for classification, see the classification `predict` reference page; for regression, see the regression `predict` reference page.

For example, to find the predicted classification of a point at the mean of the `ionosphere` data:

```
load ionosphere % contains X and Y variables
ctree = ClassificationTree.fit(X,Y);
Ynew = predict(ctree,mean(X))
```

```
Ynew =
    'g'
```

To find the predicted MPG of a point at the mean of the `carsmall` data:

```
load carsmall % contains Horsepower, Weight, MPG
X = [Horsepower Weight];
rtree = RegressionTree.fit(X,MPG);
```



```
Ynew = predict(rtree,mean(X))
```

```
Ynew =  
    28.7931
```

Improving Classification Trees and Regression Trees

You can tune trees by setting name-value pairs in `ClassificationTree.fit` and `RegressionTree.fit`. The remainder of this section describes how to determine the quality of a tree, how to decide which name-value pairs to set, and how to control the size of a tree:

- “Examining Resubstitution Error” on page 13-37
- “Cross Validation” on page 13-38
- “Control Depth or “Leafiness”” on page 13-38
- “Pruning” on page 13-42

Examining Resubstitution Error

Resubstitution error is the difference between the response training data and the predictions the tree makes of the response based on the input training data. If the resubstitution error is high, you cannot expect the predictions of the tree to be good. However, having low resubstitution error does not guarantee good predictions for new data. Resubstitution error is often an overly optimistic estimate of the predictive error on new data.

Example: Resubstitution Error of a Classification Tree. Examine the resubstitution error of a default classification tree for the Fisher iris data:

```
load fisheriris  
ctree = ClassificationTree.fit(meas,species);  
resuberror = resubLoss(ctree)
```

```
resuberror =  
    0.0200
```

The tree classifies nearly all the Fisher iris data correctly.

Cross Validation

To get a better sense of the predictive accuracy of your tree for new data, cross validate the tree. By default, cross validation splits the training data into 10 parts at random. It trains 10 new trees, each one on nine parts of the data. It then examines the predictive accuracy of each new tree on the data not included in training that tree. This method gives a good estimate of the predictive accuracy of the resulting tree, since it tests the new trees on new data.

Example: Cross Validating a Regression Tree. Examine the resubstitution and cross-validation accuracy of a regression tree for predicting mileage based on the `carsmall` data:

```
load carsmall
X = [Acceleration Displacement Horsepower Weight];
rtree = RegressionTree.fit(X,MPG);
resuberror = resubLoss(rtree)

resuberror =
    4.7188
```

The resubstitution loss for a regression tree is the mean-squared error. The resulting value indicates that a typical predictive error for the tree is about the square root of 4.7, or a bit over 2.

Now calculate the error by cross validating the tree:

```
cvrtree = crossval(rtree);
cvloss = kfoldLoss(cvrtree)

cvloss =
    23.4808
```

The cross-validated loss is almost 25, meaning a typical predictive error for the tree on new data is about 5. This demonstrates that cross-validated loss is usually higher than simple resubstitution loss.

Control Depth or “Leafiness”

When you grow a decision tree, consider its simplicity and predictive power. A deep tree with many leaves is usually highly accurate on the training data.

However, the tree is not guaranteed to show a comparable accuracy on an independent test set. A leafy tree tends to overtrain, and its test accuracy is often far less than its training (resubstitution) accuracy. In contrast, a shallow tree does not attain high training accuracy. But a shallow tree can be more robust — its training accuracy could be close to that of a representative test set. Also, a shallow tree is easy to interpret.

If you do not have enough data for training and test, estimate tree accuracy by cross validation.

For an alternative method of controlling the tree depth, see “Pruning” on page 13-42.

Example: Selecting Appropriate Tree Depth. This example shows how to control the depth of a decision tree, and how to choose an appropriate depth.

- 1 Load the ionosphere data:

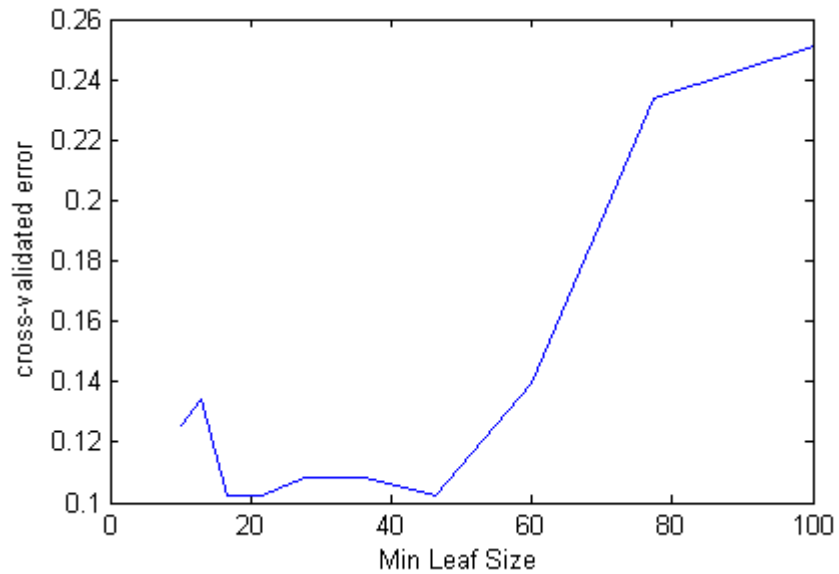
```
load ionosphere
```

- 2 Generate minimum leaf occupancies for classification trees from 10 to 100, spaced exponentially apart:

```
leafs = logspace(1,2,10);
```

- 3 Create cross validated classification trees for the ionosphere data with minimum leaf occupancies from leafs:

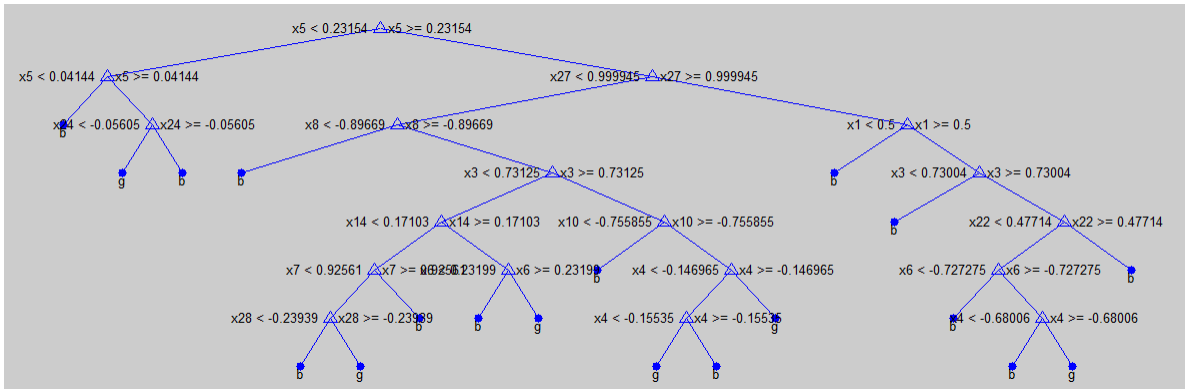
```
N = numel(leafs);
err = zeros(N,1);
for n=1:N
    t = ClassificationTree.fit(X,Y,'crossval','on',...
        'minleaf',leafs(n));
    err(n) = kfoldLoss(t);
end
plot(leafs,err);
xlabel('Min Leaf Size');
ylabel('cross-validated error');
```



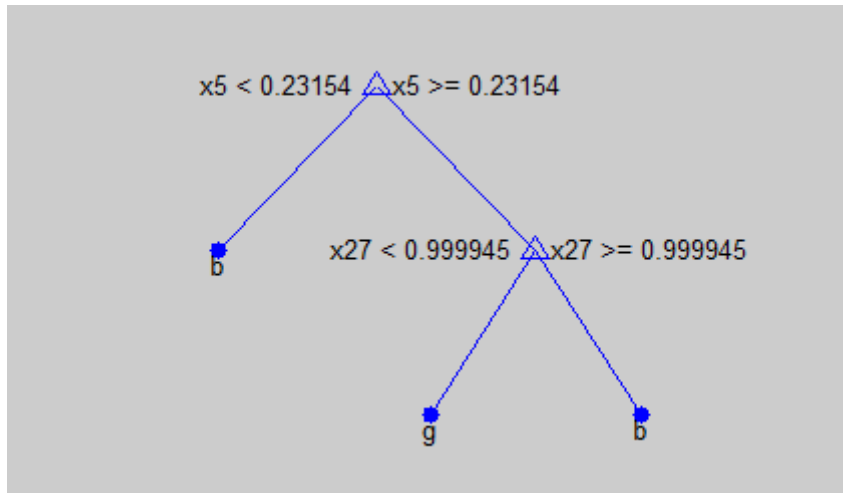
The best leaf size is between about 20 and 50 observations per leaf.

- 4 Compare the near-optimal tree with at least 40 observations per leaf with the default tree, which uses 10 observations per parent node and 1 observation per leaf.

```
DefaultTree = ClassificationTree.fit(X,Y);  
view(DefaultTree,'mode','graph')
```



```
OptimalTree = ClassificationTree.fit(X,Y,'minleaf',40);
view(OptimalTree,'mode','graph')
```



```
resubOpt = resubLoss(OptimalTree);
lossOpt = kfoldLoss(crossval(OptimalTree));
resubDefault = resubLoss(DefaultTree);
lossDefault = kfoldLoss(crossval(DefaultTree));
resubOpt,resubDefault,lossOpt,lossDefault
```

```
resubOpt =
    0.0883
```

```
resubDefault =  
    0.0114  
  
lossOpt =  
    0.1054  
  
lossDefault =  
    0.1026
```

The near-optimal tree is much smaller and gives a much higher resubstitution error. Yet it gives similar accuracy for cross-validated data.

Pruning

Pruning optimizes tree depth (leafiness) is by merging leaves on the same tree branch. “Control Depth or “Leafiness”” on page 13-38 describes one method for selecting the optimal depth for a tree. Unlike in that section, you do not need to grow a new tree for every node size. Instead, grow a deep tree, and prune it to the level you choose.

Prune a tree at the command line using the `prune` method (classification) or `prune` method (regression). Alternatively, prune a tree interactively with the tree viewer:

```
view(tree, 'mode', 'graph')
```

To prune a tree, the tree must contain a pruning sequence. By default, both `ClassificationTree.fit` and `RegressionTree.fit` calculate a pruning sequence for a tree during construction. If you construct a tree with the 'Prune' name-value pair set to 'off', or if you prune a tree to a smaller level, the tree does not contain the full pruning sequence. Generate the full pruning sequence with the `prune` method (classification) or `prune` method (regression).

Example: Pruning a Classification Tree. This example creates a classification tree for the ionosphere data, and prunes it to a good level.

1 Load the ionosphere data:

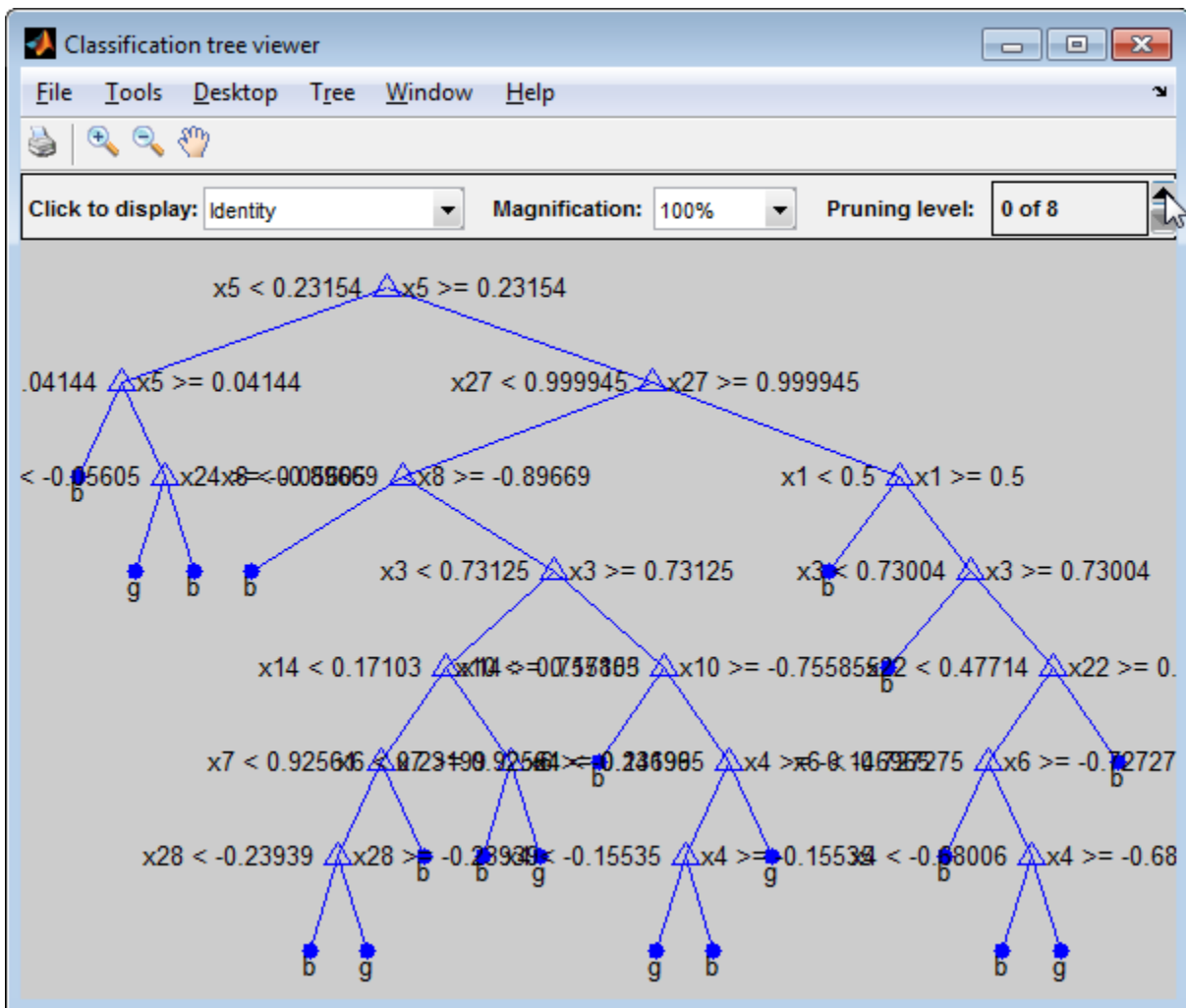
```
load ionosphere
```

- 2 Construct a default classification tree for the data:

```
tree = ClassificationTree.fit(X,Y);
```

- 3 View the tree in the interactive viewer:

```
view(tree, 'mode', 'graph')
```

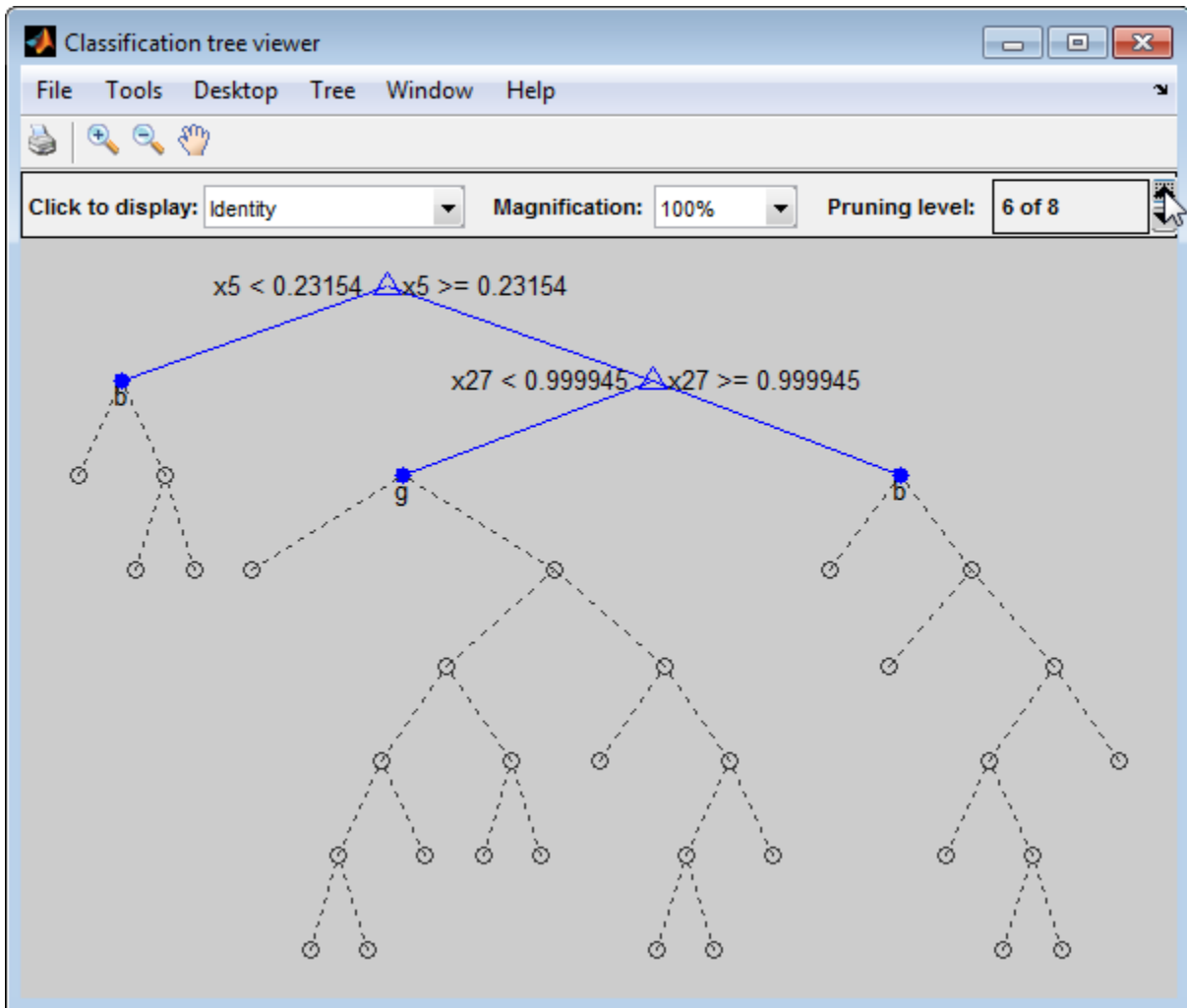


- 4** Find the optimal pruning level by minimizing cross-validated loss:

```
[~,~,~,bestlevel] = cvLoss(tree,...  
    'subtrees','all','treesize','min')
```

```
bestlevel =  
    6
```

- 5** Prune the tree to level 6 in the interactive viewer:



The pruned tree is the same as the near-optimal tree in “Example: Selecting Appropriate Tree Depth” on page 13-39.

- 6 Set 'treesize' to 'se' (default) to find the maximal pruning level for which the tree error does not exceed the error from the best level plus one standard deviation:

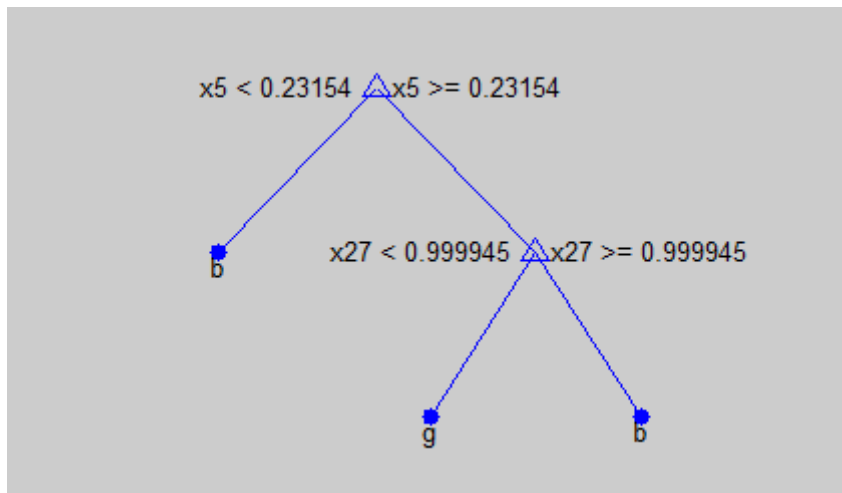
```
[~,~,~,bestlevel] = cvLoss(tree,'subtrees','all')

bestlevel =
    6
```

In this case the level is the same for either setting of 'treesize'.

7 Prune the tree to use it for other purposes:

```
tree = prune(tree,'Level',6);
view(tree,'mode','graph')
```



Alternative: `classregtree`

The `ClassificationTree` and `RegressionTree` classes are new in MATLAB R2011a. Previously, you represented both classification trees and regression trees with a `classregtree` object. The new classes provide all the functionality of the `classregtree` class, and are more convenient when used in conjunction with “Ensemble Methods” on page 13-54.

Before the `classregtree` class, there were `treefit`, `treedisp`, `treeval`, `treeprune`, and `treetest` functions. Statistics Toolbox software maintains these only for backward compatibility.

Example: Creating Classification Trees Using `classregtree`

This example uses Fisher's iris data in `fisheriris.mat` to create a classification tree for predicting species using measurements of sepal length, sepal width, petal length, and petal width as predictors. Here, the predictors are continuous and the response is categorical.

- 1 Load the data and use the `classregtree` constructor of the `classregtree` class to create the classification tree:

```
load fisheriris

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})

t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica
```

`t` is a `classregtree` object and can be operated on with any class method.

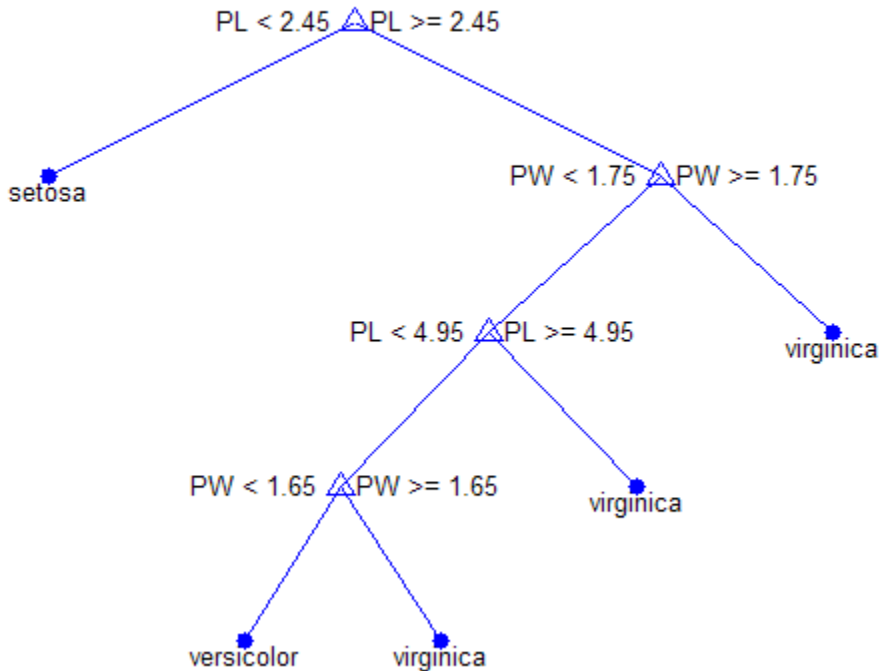
- 2 Use the `type` method of the `classregtree` class to show the type of the tree:

```
treetype = type(t)
treetype =
classification
```

`classregtree` creates a classification tree because `species` is a cell array of strings, and the response is assumed to be categorical.

- 3 To view the tree, use the `view` method of the `classregtree` class:

```
view(t)
```



The tree predicts the response values at the circular leaf nodes based on a series of questions about the iris at the triangular branching nodes. A true answer to any question follows the branch to the left. A false follows the branch to the right.

- 4 The tree does not use sepal measurements for predicting species. These can go unmeasured in new data, and you can enter them as NaN values for predictions. For example, to use the tree to predict the species of an iris with petal length 4.8 and petal width 1.6, type:

```
predicted = t([NaN NaN 4.8 1.6])
predicted =
  'versicolor'
```

The object allows for functional evaluation, of the form $t(X)$. This is a shorthand way of calling the `eval` method of the `classregtree` class. The predicted species is the left leaf node at the bottom of the tree in the previous view.

- 5** You can use a variety of methods of the `classregtree` class, such as `cutvar` and `cuttype` to get more information about the split at node 6 that makes the final distinction between `versicolor` and `virginica`:

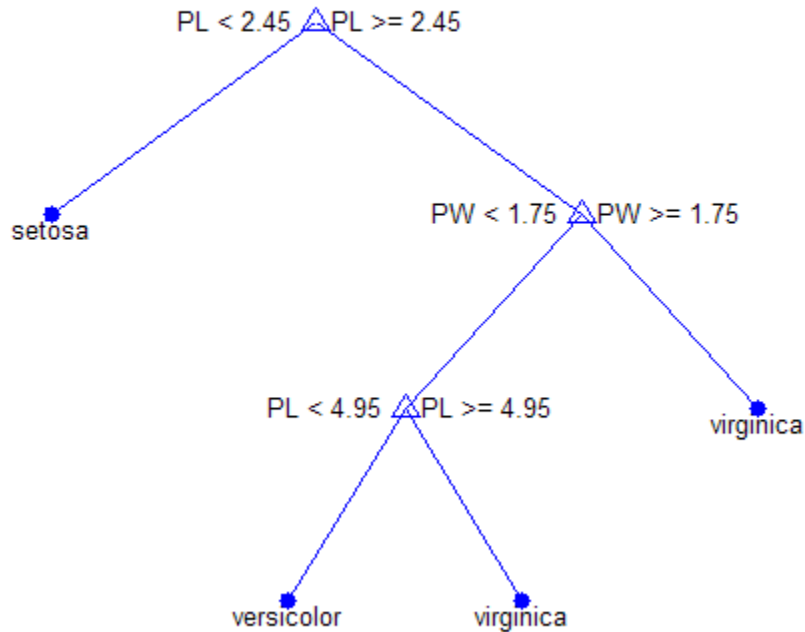
```
var6 = cutvar(t,6) % What variable determines the split?
var6 =
    'PW'

type6 = cuttype(t,6) % What type of split is it?
type6 =
    'continuous'
```

- 6** Classification trees fit the original (training) data well, but can do a poor job of classifying new values. Lower branches, especially, can be strongly affected by outliers. A simpler tree often avoids overfitting. You can use the `prune` method of the `classregtree` class to find the next largest tree from an optimal pruning sequence:

```
pruned = prune(t, 'level', 1)
pruned =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  class = versicolor
7  class = virginica

view(pruned)
```



To find the best classification tree, employing the techniques of resubstitution and cross validation, use the test method of the `classregtree` class.

Example: Creating Regression Trees Using `classregtree`

This example uses the data on cars in `carsmall.mat` to create a regression tree for predicting mileage using measurements of weight and the number of cylinders as predictors. Here, one predictor (weight) is continuous and the other (cylinders) is categorical. The response (mileage) is continuous.

- 1 Load the data and use the `classregtree` constructor of the `classregtree` class to create the regression tree:

```

load carsmall

t = classregtree([Weight, Cylinders],MPG,...
                 'cat',2,'splitmin',20,...
                 'names',{'W','C'})

t =

Decision tree for regression
1  if W<3085.5 then node 2 elseif W>=3085.5 then node 3 else 23.7181
2  if W<2371 then node 4 elseif W>=2371 then node 5 else 28.7931
3  if C=8 then node 6 elseif C in {4 6} then node 7 else 15.5417
4  if W<2162 then node 8 elseif W>=2162 then node 9 else 32.0741
5  if C=6 then node 10 elseif C=4 then node 11 else 25.9355
6  if W<4381 then node 12 elseif W>=4381 then node 13 else 14.2963
7  fit = 19.2778
8  fit = 33.3056
9  fit = 29.6111
10 fit = 23.25
11 if W<2827.5 then node 14 elseif W>=2827.5 then node 15 else 27.2143
12 if W<3533.5 then node 16 elseif W>=3533.5 then node 17 else 14.8696
13 fit = 11
14 fit = 27.6389
15 fit = 24.6667
16 fit = 16.6
17 fit = 14.3889

```

t is a `classregtree` object and can be operated on with any of the methods of the class.

- 2** Use the `type` method of the `classregtree` class to show the type of the tree:

```

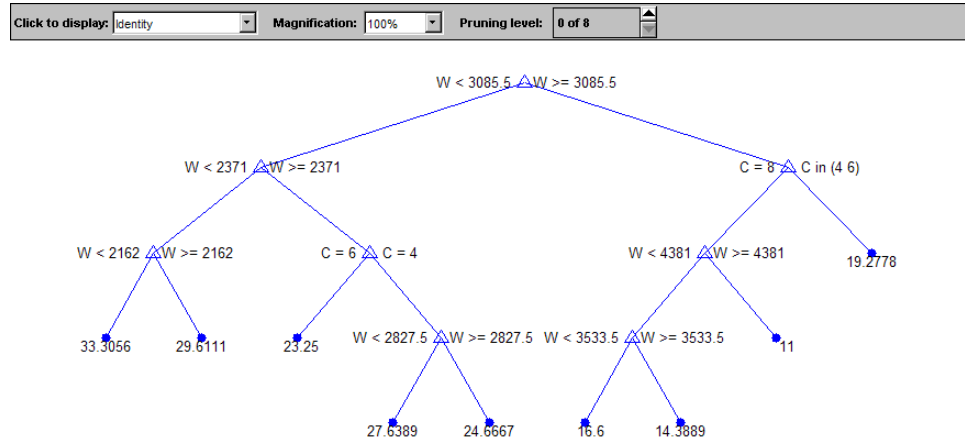
treetype = type(t)
treetype =
regression

```

`classregtree` creates a regression tree because `MPG` is a numerical vector, and the response is assumed to be continuous.

- 3** To view the tree, use the `view` method of the `classregtree` class:

view(t)



The tree predicts the response values at the circular leaf nodes based on a series of questions about the car at the triangular branching nodes. A true answer to any question follows the branch to the left; a false follows the branch to the right.

- Use the tree to predict the mileage for a 2000-pound car with either 4, 6, or 8 cylinders:

```
mileage2K = t([2000 4; 2000 6; 2000 8])
mileage2K =
    33.3056
    33.3056
    33.3056
```

The object allows for functional evaluation, of the form `t(X)`. This is a shorthand way of calling the `eval` method of the `classregtree` class.

- The predicted responses computed above are all the same. This is because they follow a series of splits in the tree that depend only on weight, terminating at the leftmost leaf node in the view above. A 4000-pound car, following the right branch from the top of the tree, leads to different predicted responses:

```
mileage4K = t([4000 4; 4000 6; 4000 8])
```



```
mileage4K =  
    19.2778  
    19.2778  
    14.3889
```

- 6** You can use a variety of other methods of the `classregtree` class, such as `cutvar`, `cuttype`, and `cutcategories`, to get more information about the split at node 3 that distinguishes the 8-cylinder car:

```
var3 = cutvar(t,3) % What variable determines the split?  
var3 =  
    'C'  
  
type3 = cuttype(t,3) % What type of split is it?  
type3 =  
    'categorical'  
  
c = cutcategories(t,3) % Which classes are sent to the left  
                        % child node, and which to the right?  
c =  
    [8]    [1x2 double]  
c{1}  
ans =  
    8  
c{2}  
ans =  
    4    6
```

Regression trees fit the original (training) data well, but may do a poor job of predicting new values. Lower branches, especially, may be strongly affected by outliers. A simpler tree often avoids overfitting. To find the best regression tree, employing the techniques of resubstitution and cross validation, use the `test` method of the `classregtree` class.

Ensemble Methods

In this section...

- “Framework for Ensemble Learning” on page 13-54
- “Basic Ensemble Examples” on page 13-64
- “Test Ensemble Quality” on page 13-66
- “Classification with Imbalanced Data” on page 13-71
- “Classification: Imbalanced Data or Unequal Misclassification Costs” on page 13-76
- “Classification with Many Categorical Levels” on page 13-83
- “Surrogate Splits” on page 13-88
- “LPBoost and TotalBoost for Small Ensembles” on page 13-93
- “Ensemble Regularization” on page 13-98
- “Tuning RobustBoost” on page 13-110
- “Random Subspace Classification” on page 13-114
- “TreeBagger Examples” on page 13-120
- “Ensemble Algorithms” on page 13-141

Framework for Ensemble Learning

You have several methods for melding results from many weak learners into one high-quality ensemble predictor. These methods closely follow the same syntax, so you can try different methods with minor changes in your commands.

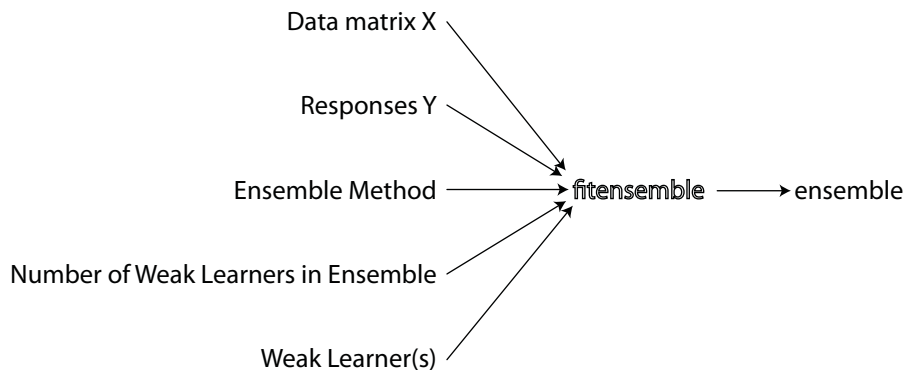
Create an ensemble with the `fitensemble` function. Its syntax is

```
ens = fitensemble(X,Y,model,numberens,learners)
```

- `X` is the matrix of data. Each row contains one observation, and each column contains one predictor variable.
- `Y` is the vector of responses, with the same number of observations as the rows in `X`.

- `model` is a string naming the type of ensemble.
- `numberens` is the number of weak learners in `ens` from each element of `learners`. So the number of elements in `ens` is `numberens` times the number of elements in `learners`.
- `learners` is either a string naming a weak learner, a weak learner template, or a cell array of such templates.

Pictorially, here is the information you need to create an ensemble:



For all classification or nonlinear regression problems, follow these steps to create an ensemble:

- 1** "Put Predictor Data in a Matrix" on page 13-56
- 2** "Prepare the Response Data" on page 13-56
- 3** "Choose an Applicable Ensemble Method" on page 13-57
- 4** "Set the Number of Ensemble Members" on page 13-60
- 5** "Prepare the Weak Learners" on page 13-61
- 6** "Call `fitensemble`" on page 13-63

Put Predictor Data in a Matrix

All supervised learning methods start with a data matrix, usually called X in this documentation. Each row of X represents one observation. Each column of X represents one variable, or predictor.

Prepare the Response Data

You can use a wide variety of data types for response data.

- For regression ensembles, Y must be a numeric vector with the same number of elements as the number of rows of X .
- For classification ensembles, Y can be any of the following data types. This table also contains the method of including missing entries.

Data Type	Missing Entry
Numeric vector	NaN
Categorical vector	<undefined>
Character array	Row of spaces
Cell array of strings	' '
Logical vector	(not possible to represent)

`fitensemble` ignores missing values in Y when creating an ensemble.

For example, suppose your response data consists of three observations in the following order: true, false, true. You could express Y as:

- `[1;0;1]` (numeric vector)
- `nominal({'true','false','true'})` (categorical vector)
- `[true;false;true]` (logical vector)
- `['true ','false ','true ']` (character array, padded with spaces so each row has the same length)
- `{'true','false','true'}` (cell array of strings)

Use whichever data type is most convenient. Because you cannot represent missing values with logical entries, do not use logical entries when you have missing values in Y .

Choose an Applicable Ensemble Method

`fitensemble` uses one of these algorithms to create an ensemble.

- For classification with two classes:
 - 'AdaBoostM1'
 - 'LogitBoost'
 - 'GentleBoost'
 - 'RobustBoost' (requires an Optimization Toolbox license)
 - 'LPBoost' (requires an Optimization Toolbox license)
 - 'TotalBoost' (requires an Optimization Toolbox license)
 - 'RUSBoost'
 - 'Subspace'
 - 'Bag'
- For classification with three or more classes:
 - 'AdaBoostM2'
 - 'LPBoost' (requires an Optimization Toolbox license)
 - 'TotalBoost' (requires an Optimization Toolbox license)
 - 'RUSBoost'
 - 'Subspace'
 - 'Bag'
- For regression:
 - 'LSBoost'
 - 'Bag'

'Bag' applies to all methods. When using 'Bag', indicate whether you want a classifier or regressor with the type name-value pair set to 'classification' or 'regression'.

For descriptions of the various algorithms, see “Ensemble Algorithms” on page 13-141.

See “Suggestions for Choosing an Appropriate Ensemble Algorithm” on page 13-59.

This table lists characteristics of the various algorithms. In the table titles:

- **Regress.** — Regression
- **Classif.** — Classification
- **Preds.** — Predictors
- **Imbalance** — Good for imbalanced data (one class has many more observations than the other)
- **Stop** — Algorithm self-terminates
- **Sparse** — Requires fewer weak learners than other ensemble algorithms

Algorithm	Regress.	Binary Classif.	Binary Classif. Multi-Level Preds.	Classif. 3+ Classes	Class Imbalance	Stop	Sparse
Bag	×	×		×			
AdaBoostM1		×					
AdaBoostM2				×			
LogitBoost		×	×				
GentleBoost		×	×				
RobustBoost		×					
LPBoost		×		×		×	×
TotalBoost		×		×		×	×

Algorithm	Regress.	Binary Classif.	Binary Classif. Multi-Level Preds.	Classif. 3+ Classes	Class Imbalance	Stop	Sparse
RUSBoost		×		×	×		
LSBoost	×						
Subspace		×		×			

RobustBoost, LPBoost, and TotalBoost require an Optimization Toolbox license. Try TotalBoost before LPBoost, as TotalBoost can be more robust.

Suggestions for Choosing an Appropriate Ensemble Algorithm.

- **Regression** — Your choices are LSBoost or Bag. See “General Characteristics of Ensemble Algorithms” on page 13-60 for the main differences between boosting and bagging.
- **Binary Classification** — Try AdaBoostM1 first, with these modifications:

Data Characteristic	Recommended Algorithm
Many predictors	Subspace
Skewed data (many more observations of one class)	RUSBoost
Categorical predictors with over 31 levels	LogitBoost or GentleBoost
Label noise (some training data has the wrong class)	RobustBoost
Many observations	Avoid LPBoost, TotalBoost, and Bag

- **Multiclass Classification** — Try AdaBoostM2 first, with these modifications:

Data Characteristic	Recommended Algorithm
Many predictors	Subspace
Skewed data (many more observations of one class)	RUSBoost
Many observations	Avoid LPBoost, TotalBoost, and Bag

For details of the algorithms, see “Ensemble Algorithms” on page 13-141.

General Characteristics of Ensemble Algorithms.

- Bag generally constructs deep trees. This construction is both time consuming and memory-intensive. This also leads to relatively slow predictions.
- Boost algorithms generally use very shallow trees. This construction uses relatively little time or memory. However, for effective predictions, boosted trees might need more ensemble members than bagged trees. Therefore it is not always clear which class of algorithms is superior.
- Bag can estimate the generalization error without additional cross validation. See `oobLoss`.
- Except for Subspace, all boosting and bagging algorithms are based on tree learners. Subspace can use either discriminant analysis or k -nearest neighbor learners.

For details of the characteristics of individual ensemble members, see “Characteristics of Algorithms” on page 13-7.

Set the Number of Ensemble Members

Choosing the size of an ensemble involves balancing speed and accuracy.

- Larger ensembles take longer to train and to generate predictions.
- Some ensemble algorithms can become overtrained (inaccurate) when too large.

To set an appropriate size, consider starting with several dozen to several hundred members in an ensemble, training the ensemble, and then checking the ensemble quality, as in “Example: Test Ensemble Quality” on page 13-66. If it appears that you need more members, add them using the `resume` method (classification) or the `resume` method (regression). Repeat until adding more members does not improve ensemble quality.

Tip For classification, the `LPBoost` and `TotalBoost` algorithms are self-terminating, meaning you do not have to investigate the appropriate ensemble size. Try setting `numberens` to 500. The algorithms usually terminate with fewer members.

Prepare the Weak Learners

Currently the weak learner types are:

- 'Discriminant' (for Subspace ensemble)
- 'KNN' (for Subspace ensemble)
- 'Tree' (for any ensemble except Subspace)

There are two ways to set the weak learner type in the ensemble:

- To create an ensemble with default weak learner options, pass in the string as the weak learner. For example,

```
ens = fitensemble(X,Y, 'AdaBoostM2', 50, 'Tree');
% or
ens = fitensemble(X,Y, 'Subspace', 50, 'KNN');
```

- To create an ensemble with nondefault weak learner options, create a nondefault weak learner using the appropriate `template` method. For example, if you have missing data, and want to use trees with surrogate splits for better accuracy:

```
templ = ClassificationTree.template('Surrogate', 'on');
ens = fitensemble(X,Y, 'AdaBoostM2', 50, templ);
```

To grow trees with roughly 10 leaf nodes per tree:

```
templ = ClassificationTree.template('MinLeaf',size(X,1)/10);  
ens = fitensemble(X,Y,'AdaBoostM2',50,templ);
```

While you can give `fitensemble` a cell array of learner templates, the most common usage is to give just one weak learner template.

For examples using a template, see “Example: Unequal Classification Costs” on page 13-78 and “Surrogate Splits” on page 13-88.

Decision trees can handle NaN values in X . Such values are called “missing.” If you have some missing values in a row of X , a decision tree finds optimal splits using nonmissing values only. If an entire row consists of NaN, `fitensemble` ignores that row. If you have data with a large fraction of missing values in X , use surrogate decision splits. For examples of surrogate splits, see “Example: Unequal Classification Costs” on page 13-78 and “Surrogate Splits” on page 13-88.

Common Settings for Tree Weak Learners.

- The depth of a weak learner tree makes a difference for training time, memory usage, and predictive accuracy. You control the depth with two parameters:
 - `MinLeaf` — Each leaf has at least `MinLeaf` observations. Set small values of `MinLeaf` to get a deep tree.
 - `MinParent` — Each branch node in the tree has at least `MinParent` observations. Set small values of `MinParent` to get a deep tree.

If you supply both `MinParent` and `MinLeaf`, the learner uses the setting that gives larger leaves:

```
MinParent = max(MinParent,2*MinLeaf)
```

- `Surrogate` — Grow decision trees with surrogate splits when `Surrogate` is 'on'. Use surrogate splits when your data has missing values.

Note Surrogate splits cause training to be slower and use more memory.

Call `fitensemble`

The syntax of `fitensemble` is

```
ens = fitensemble(X,Y,model,numberens,learners)
```

- `X` is the matrix of data. Each row contains one observation, and each column contains one predictor variable.
- `Y` is the responses, with the same number of observations as rows in `X`.
- `model` is a string naming the type of ensemble.
- `numberens` is the number of weak learners in `ens` from each element of `learners`. So the number of elements in `ens` is `numberens` times the number of elements in `learners`.
- `learners` is a string naming a weak learner, a weak learner template, or a cell array of such strings and templates.

The result of `fitensemble` is an ensemble object, suitable for making predictions on new data. For a basic example of creating a classification ensemble, see “Create a Classification Ensemble” on page 13-64. For a basic example of creating a regression ensemble, see “Creating a Regression Ensemble” on page 13-65.

Where to Set Name-Value Pairs. There are several name-value pairs you can pass to `fitensemble`, and several that apply to the weak learners (`ClassificationDiscriminant.template`, `ClassificationKNN.template`, `ClassificationTree.template` and `RegressionTree.template`). To determine which option (name-value pair) is appropriate, the ensemble or the weak learner:

- Use template name-value pairs to control the characteristics of the weak learners.
- Use `fitensemble` name-value pairs to control the ensemble as a whole, either for algorithms or for structure.

For example, to have an ensemble of boosted classification trees with each tree deeper than the default, set the `ClassificationTree.template` name-value pairs (`MinLeaf` and `MinParent`) to smaller values than the defaults. This causes the trees to be leafier (deeper).

To name the predictors in the ensemble (part of the structure of the ensemble), use the `PredictorNames` name-value pair in `fitensemble`.

Basic Ensemble Examples

Create a Classification Ensemble

Create a classification tree ensemble for the Fisher iris data, and use it to predict the classification of a flower with average measurements.

- 1 Load the data:

```
load fisheriris
```

- 2 The predictor data `X` is the `meas` matrix.

- 3 The response data `Y` is the `species` cell array.

- 4 For classification trees with three or more classes, “Suggestions for Choosing an Appropriate Ensemble Algorithm” on page 13-59 suggests using an `'AdaBoostM2'` ensemble.

- 5 For this example, arbitrarily take an ensemble of 100 trees.

- 6 Use a default tree template.

- 7 Create the ensemble:

```
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree')

ens =
classreg.learning.classif.ClassificationEnsemble:
    PredictorNames: {'x1' 'x2' 'x3' 'x4'}
    CategoricalPredictors: []
    ResponseName: 'Y'
    ClassNames: {'setosa' 'versicolor' 'virginica'}
    ScoreTransform: 'none'
    NObservations: 150
    NTrained: 100
    Method: 'AdaBoostM2'
    LearnerNames: {'Tree'}
```

```
ReasonForTermination: [1x77 char]
                   FitInfo: [100x1 double]
                   FitInfoDescription: [2x83 char]
```

- 8 Predict the classification of a flower with average measurements:

```
flower = predict(ens,mean(meas))
```

```
flower =
    'versicolor'
```

Creating a Regression Ensemble

Create a regression ensemble to predict mileage of cars based on their horsepower and weight, trained on the `carsmall` data. Use the resulting ensemble to predict the mileage of a car with 150 horsepower weighing 2750 lbs.

- 1 Load the data:

```
load carsmall
```

- 2 Prepare the input data.

```
X = [Horsepower Weight];
```

- 3 The response data Y is MPG.

- 4 The only boosted regression ensemble type is 'LSBoost'.

- 5 For this example, arbitrarily take an ensemble of 100 trees.

- 6 Use a default tree template.

- 7 Create the ensemble:

```
ens = fitensemble(X,MPG,'LSBoost',100,'Tree')
```

```
ens =
classreg.learning.regr.RegressionEnsemble:
    PredictorNames: {'x1' 'x2'}
    CategoricalPredictors: []
```

```
      ResponseName: 'Y'  
      ResponseTransform: 'none'  
      NObservations: 94  
      NTrained: 100  
      Method: 'LSBoost'  
      LearnerNames: {'Tree'}  
      ReasonForTermination: [1x77 char]  
      FitInfo: [100x1 double]  
      FitInfoDescription: [2x83 char]  
      Regularization: []
```

- 8** Predict the mileage of a car with 150 horsepower weighing 2750 lbs:

```
mileage = ens.predict([150 2750])  
  
mileage =  
    22.6735
```

Test Ensemble Quality

Usually you cannot evaluate the predictive quality of an ensemble based on its performance on training data. Ensembles tend to “overtrain,” meaning they produce overly optimistic estimates of their predictive power. This means the result of `resubLoss` for classification (`resubLoss` for regression) usually indicates lower error than you get on new data.

To obtain a better idea of the quality of an ensemble, use one of these methods:

- Evaluate the ensemble on an independent test set (useful when you have a lot of training data).
- Evaluate the ensemble by cross validation (useful when you don’t have a lot of training data).
- Evaluate the ensemble on out-of-bag data (useful when you create a bagged ensemble with `fitensemble`).

Example: Test Ensemble Quality

This example uses a bagged ensemble so it can use all three methods of evaluating ensemble quality.

- 1 Generate an artificial dataset with 20 predictors. Each entry is a random number from 0 to 1. The initial classification:

$Y = 1$ when $X(1) + X(2) + X(3) + X(4) + X(5) > 2.5$
 $Y = 0$ otherwise.

```
rng(1,'twister') % for reproducibility
X = rand(2000,20);
Y = sum(X(:,1:5),2) > 2.5;
```

In addition, to add noise to the results, randomly switch 10% of the classifications:

```
idx = randsample(2000,200);
Y(idx) = ~Y(idx);
```

2 Independent Test Set

Create independent training and test sets of data. Use 70% of the data for a training set by calling `cvpartition` using the `holdout` option:

```
cvpart = cvpartition(Y,'holdout',0.3);
Xtrain = X(training(cvpart),:);
Ytrain = Y(training(cvpart),:);
Xtest = X(test(cvpart),:);
Ytest = Y(test(cvpart),:);
```

- 3 Create a bagged classification ensemble of 200 trees from the training data:

```
bag = fitensemble(Xtrain,Ytrain,'Bag',200,'Tree',...
    'type','classification')
```

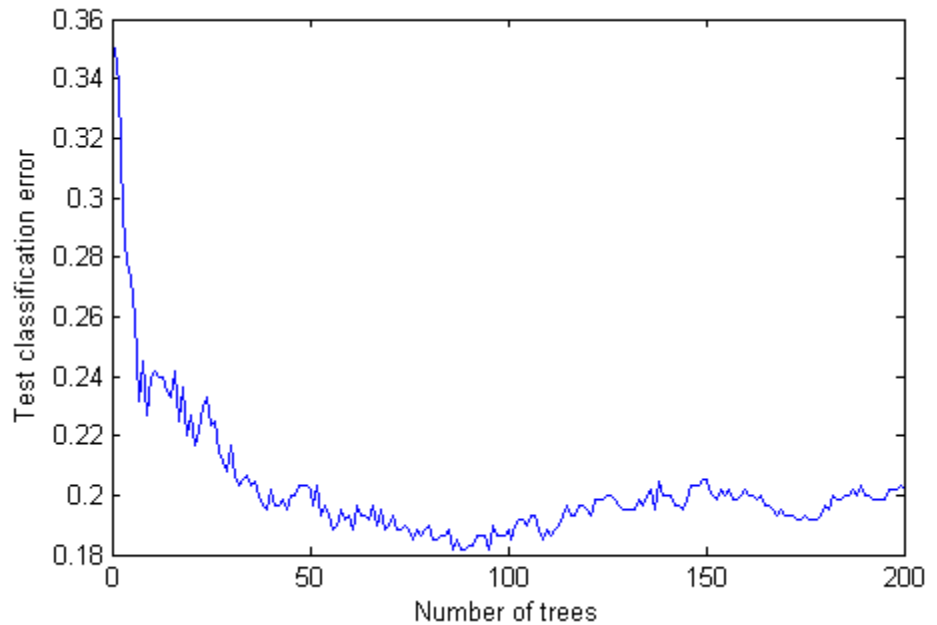
```
bag =
```

```
classreg.learning.classif.ClassificationBaggedEnsemble:
    PredictorNames: {1x20 cell}
    CategoricalPredictors: []
    ResponseName: 'Y'
    ClassNames: [0 1]
    ScoreTransform: 'none'
    NObservations: 1400
```

```
      NTrained: 200
      Method: 'Bag'
      LearnerNames: {'Tree'}
      ReasonForTermination: [1x77 char]
      FitInfo: []
      FitInfoDescription: 'None'
      FResample: 1
      Replace: 1
      UseObsForLearner: [1400x200 logical]
```

- 4** Plot the loss (misclassification) of the test data as a function of the number of trained trees in the ensemble:

```
figure;
plot(loss(bag,Xtest,Ytest,'mode','cumulative'));
xlabel('Number of trees');
ylabel('Test classification error');
```



5 Cross Validation

Generate a five-fold cross-validated bagged ensemble:

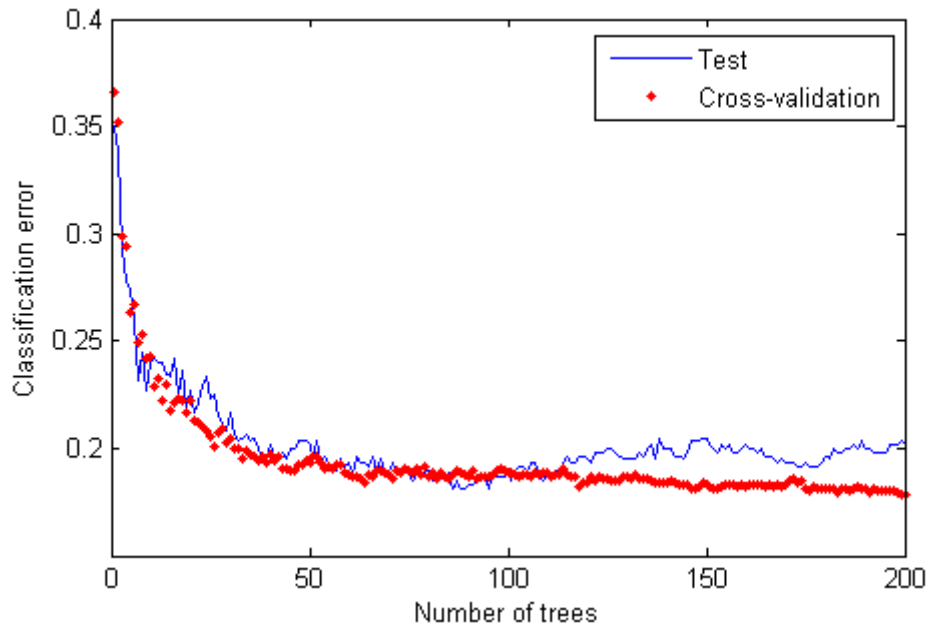
```
cv = fitensemble(X,Y,'Bag',200,'Tree',...
    'type','classification','kfold',5)

cv =

classreg.learning.partition.ClassificationPartitionedEnsemble:
    CrossValidatedModel: 'Bag'
    PredictorNames: {1x20 cell}
    CategoricalPredictors: []
    ResponseName: 'Y'
    NObservations: 2000
    KFold: 5
    Partition: [1x1 cvpartition]
    NTrainedPerFold: [200 200 200 200 200]
    ClassNames: [0 1]
    ScoreTransform: 'none'
```

- 6** Examine the cross-validation loss as a function of the number of trees in the ensemble:

```
figure;
plot(loss(bag,Xtest,Ytest,'mode','cumulative'));
hold
plot(kfoldLoss(cv,'mode','cumulative'),'r.');
hold off;
xlabel('Number of trees');
ylabel('Classification error');
legend('Test','Cross-validation','Location','NE');
```

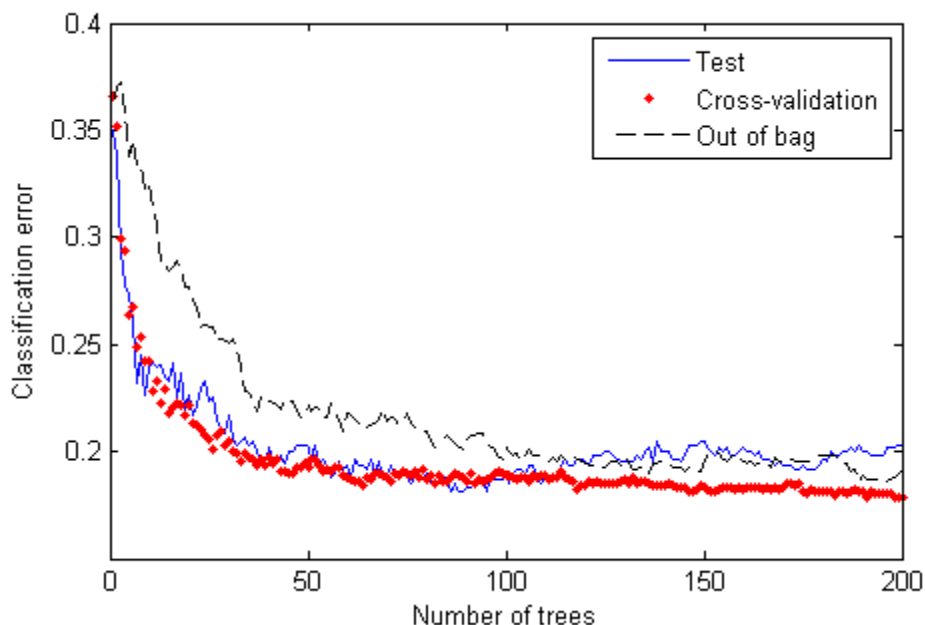


Cross validating gives comparable estimates to those of the independent set.

7 Out-of-Bag Estimates

Generate the loss curve for out-of-bag estimates, and plot it along with the other curves:

```
figure;
plot(loss(bag,Xtest,Ytest,'mode','cumulative'));
hold
plot(kfoldLoss(cv,'mode','cumulative'),'r. ');
plot(oobLoss(bag,'mode','cumulative'),'k-- ');
hold off;
xlabel('Number of trees');
ylabel('Classification error');
legend('Test','Cross-validation','Out of bag','Location','NE');
```



The out-of-bag estimates are again comparable to those of the other methods.

Classification with Imbalanced Data

This example shows how to classify when one class has many more observations than another. Try the RUSBoost algorithm first, because it is designed to handle this case.

This example uses the “Cover type” data from the UCI machine learning archive, described in <http://archive.ics.uci.edu/ml/datasets/Covertype>. The data classifies types of forest (ground cover), based on predictors such as elevation, soil type, and distance to water. The data has over 500,000 observations and over 50 predictors, so training and using a classifier is time consuming.

Blackard and Dean [1] describe a neural net classification of this data. They quote a 70.6% classification accuracy. RUSBoost obtains over 76% classification accuracy; see steps 6 and 7.

Step 1. Obtain the data.

```
urlwrite('http://archive.ics.uci.edu/ml/machine-learning-databases/covtype/
```

Then, extract the data from the `forestcover.gz` file. The data is in the `covtype.data` file.

Step 2. Import the data and prepare it for classification.

Import the data into your workspace. Extract the last data column into a variable named `Y`.

```
load covtype.data
Y = covtype(:,end);
covtype(:,end) = [];
```

Step 3. Examine the response data.

```
tabulate(Y)
```

Value	Count	Percent
1	211840	36.46%
2	283301	48.76%
3	35754	6.15%
4	2747	0.47%
5	9493	1.63%
6	17367	2.99%
7	20510	3.53%

There are hundreds of thousands of data points. Those of class 4 are less than 0.5% of the total. This imbalance indicates that RUSBoost is an appropriate algorithm.

Step 4. Partition the data for quality assessment.

Use half the data to fit a classifier, and half to examine the quality of the resulting classifier.

```
part = cvpartition(Y,'holdout',0.5);
istrain = training(part); % data for fitting
istest = test(part); % data for quality assessment
tabulate(Y(istrain))
```

Value	Count	Percent
1	105920	36.46%
2	141651	48.76%
3	17877	6.15%
4	1374	0.47%
5	4746	1.63%
6	8683	2.99%
7	10255	3.53%

Step 5. Create the ensemble.

Use deep trees for higher ensemble accuracy. To do so, set the trees to have minimal leaf size of 5. Set `LearnRate` to 0.1 in order to achieve higher accuracy as well. The data is large, and, with deep trees, creating the ensemble is time consuming.

```
t = ClassificationTree.template('minleaf',5);
tic
rusTree = fitensemble(covtype(istrain,:),Y(istrain),'RUSBoost',1000,t,...
    'LearnRate',0.1,'nprint',100);
toc
```

```
Training RUSBoost...
Grown weak learners: 100
Grown weak learners: 200
Grown weak learners: 300
Grown weak learners: 400
Grown weak learners: 500
Grown weak learners: 600
Grown weak learners: 700
Grown weak learners: 800
Grown weak learners: 900
Grown weak learners: 1000
Elapsed time is 5862.251154 seconds.
```

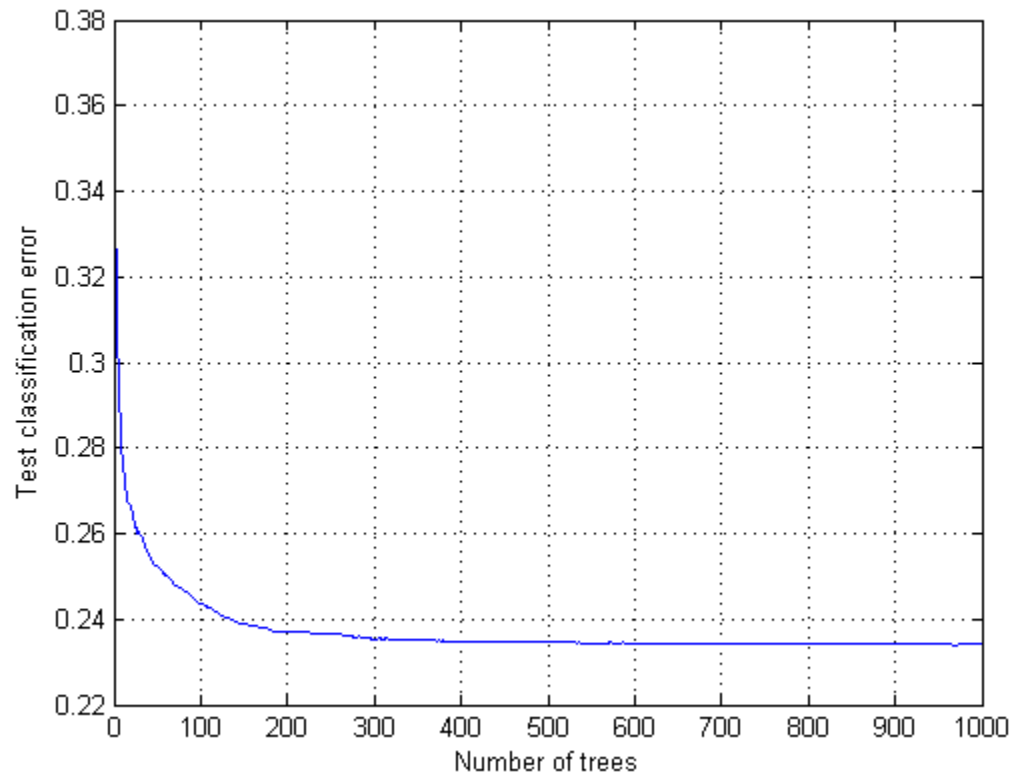
Step 6. Inspect the classification error.

Plot the classification error against the number of members in the ensemble.

```
figure;
tic
```

```
plot(loss(rusTree,covtype(istest,:),Y(istest),'mode','cumulative'));
toc
grid on;
xlabel('Number of trees');
ylabel('Test classification error');
```

Elapsed time is 851.951423 seconds.



The ensemble achieves a classification error of under 24% using 150 or more trees. It achieves the lowest error for 400 or more trees.

Examine the confusion matrix for each class as a percentage of the true class.

```
tic
Yfit = predict(rusTree,covtype(istest,:));
toc
tab = tabulate(Y(istest));
bsxfun(@divide,confusionmat(Y(istest),Yfit),tab(:,2))*100
```

Elapsed time is 774.149026 seconds.

ans =

84.2409	6.7447	0.0869	0	1.7513	0.2644	6.9118
19.3745	65.4458	2.0635	0.0198	9.3442	2.8613	0.8909
0	0.0671	90.3339	2.4557	0.6377	6.5056	0
0	0	2.9133	95.0473	0	2.0393	0
0.0211	0.2739	0.4845	0	98.7150	0.4845	0.0211
0	0.1267	3.5122	1.1746	0.4836	94.7029	0
0.2925	0.0488	0	0	0.0293	0	99.6294

All classes except class 2 have over 80% classification accuracy, and classes 3 through 7 have over 90% accuracy. But class 2 makes up close to half the data, so the overall accuracy is not that high.

Step 7. Compact the ensemble.

The ensemble is large. Remove the data using the compact method.

```
cmpctRus = compact(rusTree);
```

```
sz(1) = whos('rusTree');
sz(2) = whos('cmpctRus');
[sz(1).bytes sz(2).bytes]
```

ans =

```
1.0e+09 *
1.4479    0.7322
```

The compacted ensemble is about half the size of the original.

Remove half the trees from `cmpctRus`. This action is likely to have minimal effect on the predictive performance, based on the observation that 400 out of 1000 trees give nearly optimal accuracy.

```
cmpctRus = removeLearners(cmpctRus,[500:1000]);
```

```
sz(3) = whos('cmpctRus');  
sz(3).bytes
```

```
ans =
```

```
355576933
```

The reduced compact ensemble takes about a quarter the memory of the full ensemble. Its overall loss rate is under 24%:

```
L = loss(cmpctRus,covtype(istest,:),Y(istest))
```

```
L =
```

```
0.2346
```

The predictive accuracy on new data might differ, because the ensemble accuracy might be biased. The bias arises because the same data used for assessing the ensemble was used for reducing the ensemble size. To obtain an unbiased estimate of requisite ensemble size, you should use cross validation. However, that procedure is time consuming.

Classification: Imbalanced Data or Unequal Misclassification Costs

In many real-world applications, you might prefer to treat classes in your data asymmetrically. For example, you might have data with many more observations of one class than of any other. Or you might work on a problem in which misclassifying observations of one class has more severe consequences than misclassifying observations of another class. In such situations, you can use two optional parameters for `fitensemble`: `prior` and `cost`.

By using `prior`, you set prior class probabilities (that is, class probabilities used for training). Use this option if some classes are under- or overrepresented in your training set. For example, you might obtain your

training data by simulation. Because simulating class A is more expensive than class B, you opt to generate fewer observations of class A and more observations of class B. You expect, however, that class A and class B are mixed in a different proportion in the real world. In this case, set prior probabilities for class A and B approximately to the values you expect to observe in the real world. `fitensemble` normalizes prior probabilities to make them add up to 1; multiplying all prior probabilities by the same positive factor does not affect the result of classification.

If classes are adequately represented in the training data but you want to treat them asymmetrically, use the `cost` parameter. Suppose you want to classify benign and malignant tumors in cancer patients. Failure to identify a malignant tumor (false negative) has far more severe consequences than misidentifying benign as malignant (false positive). You should assign high cost to misidentifying malignant as benign and low cost to misidentifying benign as malignant.

You must pass misclassification costs as a square matrix with nonnegative elements. Element $C(i, j)$ of this matrix is the cost of classifying an observation into class j if the true class is i . The diagonal elements $C(i, i)$ of the cost matrix must be 0. For the previous example, you can choose malignant tumor to be class 1 and benign tumor to be class 2. Then you can set the cost matrix to

$$\begin{bmatrix} 0 & c \\ 1 & 0 \end{bmatrix}$$

where $c > 1$ is the cost of misidentifying a malignant tumor as benign. Costs are relative—multiplying all costs by the same positive factor does not affect the result of classification.

If you have only two classes, `fitensemble` adjusts their prior probabilities using $\tilde{P}_i = C_{ij}P_i$ for class $i = 1, 2$ and $j \neq i$. P_i are prior probabilities either passed into `fitensemble` or computed from class frequencies in the training data, and \tilde{P}_i are adjusted prior probabilities. Then `fitensemble` uses the default cost matrix

$$\begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

and these adjusted probabilities for training its weak learners. Manipulating the cost matrix is thus equivalent to manipulating the prior probabilities.

If you have three or more classes, `fitensemble` also converts input costs into adjusted prior probabilities. This conversion is more complex. First, `fitensemble` attempts to solve a matrix equation described in Zhou and Liu [17]. If it fails to find a solution, `fitensemble` applies the “average cost” adjustment described in Breiman et al. [5]. For more information, see Zadrozny, Langford, and Abe [16].

Example: Unequal Classification Costs

This example uses data on patients with hepatitis to see if they live or die as a result of the disease. The data is described at <http://archive.ics.uci.edu/ml/datasets/Hepatitis>.

- 1 Load the data into a file named `hepatitis.txt`:

```
s = urlread(['http://archive.ics.uci.edu/ml/' ...
    'machine-learning-databases/hepatitis/hepatitis.data']);
fid = fopen('hepatitis.txt','w');
fwrite(fid,s);
fclose(fid);
```

- 2 Load the data `hepatitis.txt` into a dataset, with variable names describing the fields in the data:

```
VarNames = {'die_or_live' 'age' 'sex' 'steroid' 'antivirals' 'fatigue' ...
    'malaise' 'anorexia' 'liver_big' 'liver_firm' 'spleen_palpable' ...
    'spiders' 'ascites' 'varices' 'bilirubin' 'alk_phosphate' 'sgot' ...
    'albumin' 'protime' 'histology'};
ds = dataset('file','hepatitis.txt','VarNames',VarNames,...
    'Delimiter',' ','ReadVarNames',false,'TreatAsEmpty','?',...
    'Format','%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f%f');
```

`ds` is a dataset with 155 observations and 20 variables:

```
size(ds)
```

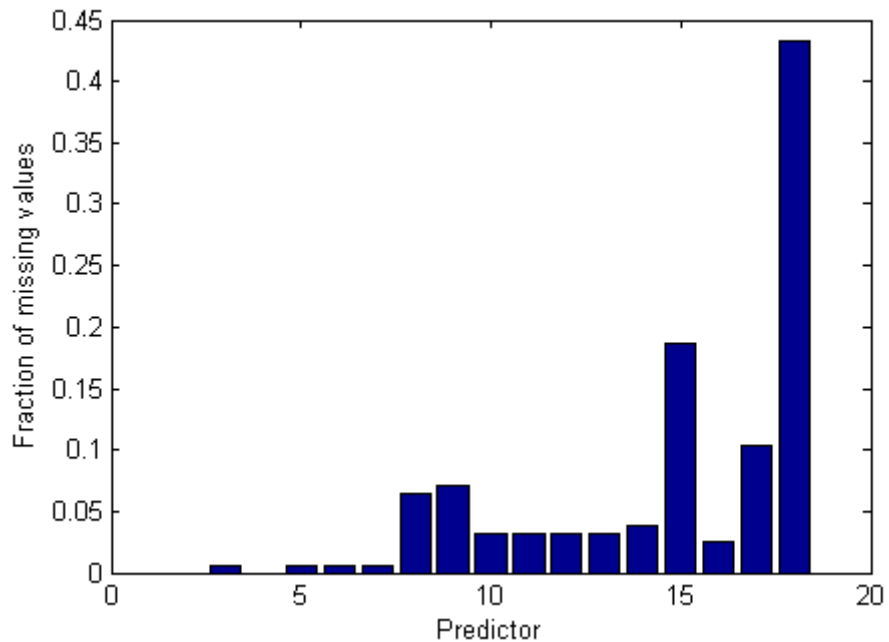
```
ans =  
    155    20
```

- 3** Convert the data in the dataset to the format for ensembles: a numeric matrix of predictors, and a cell array with outcome names: 'Die' or 'Live'. The first field in the dataset has the outcomes.

```
X = double(ds(:,2:end));  
ClassNames = {'Die' 'Live'};  
Y = ClassNames(ds.die_or_live);
```

- 4** Inspect the data for missing values:

```
figure;  
bar(sum(isnan(X),1)/size(X,1));  
xlabel('Predictor');  
ylabel('Fraction of missing values');
```



Most predictors have missing values, and one has nearly 45% of missing values. Therefore, use decision trees with surrogate splits for better accuracy. Because the dataset is small, training time with surrogate splits should be tolerable.

- 5 Create a classification tree template that uses surrogate splits:

```
rng(0,'twister') % for reproducibility
t = ClassificationTree.template('surrogate','on');
```

- 6 Examine the data or the description of the data to see which predictors are categorical:

```
X(1:5,:)
```

```
ans =
```

```
Columns 1 through 6
```

```

30.0000    2.0000    1.0000    2.0000    2.0000    2.0000
50.0000    1.0000    1.0000    2.0000    1.0000    2.0000
78.0000    1.0000    2.0000    2.0000    1.0000    2.0000
31.0000    1.0000         NaN    1.0000    2.0000    2.0000
34.0000    1.0000    2.0000    2.0000    2.0000    2.0000

```

Columns 7 through 12

```

2.0000    1.0000    2.0000    2.0000    2.0000    2.0000
2.0000    1.0000    2.0000    2.0000    2.0000    2.0000
2.0000    2.0000    2.0000    2.0000    2.0000    2.0000
2.0000    2.0000    2.0000    2.0000    2.0000    2.0000
2.0000    2.0000    2.0000    2.0000    2.0000    2.0000

```

Columns 13 through 18

```

2.0000    1.0000    85.0000    18.0000    4.0000         NaN
2.0000    0.9000   135.0000    42.0000    3.5000         NaN
2.0000    0.7000    96.0000    32.0000    4.0000         NaN
2.0000    0.7000    46.0000    52.0000    4.0000    80.0000
2.0000    1.0000         NaN   200.0000    4.0000         NaN

```

Column 19

```

1.0000
1.0000
1.0000
1.0000
1.0000

```

It appears that predictors 2 through 13 are categorical, as well as predictor 19. You can confirm this inference with the dataset description at <http://archive.ics.uci.edu/ml/datasets/Hepatitis>.

7 List the categorical variables:

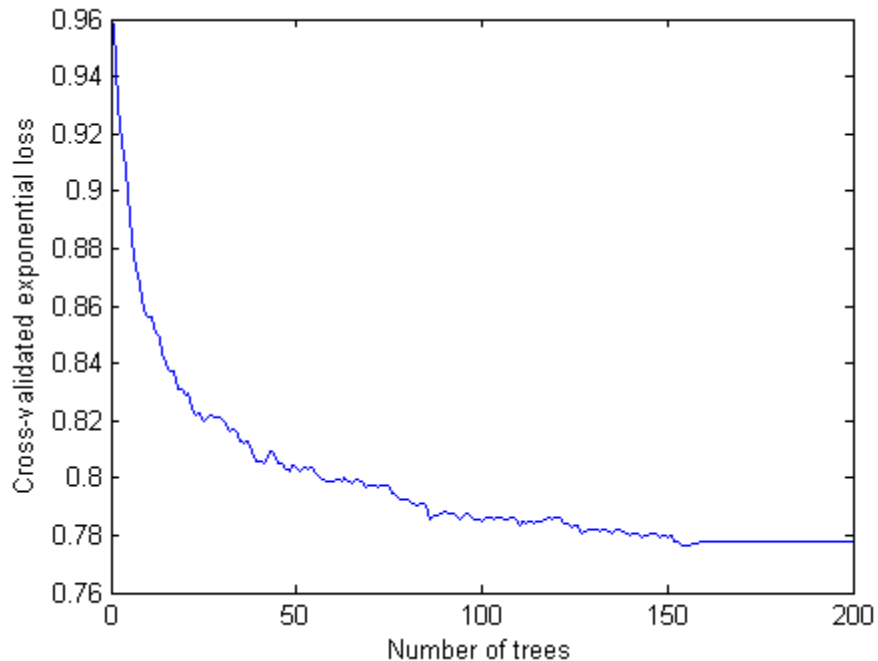
```
necat = [2:13,19];
```

8 Create a cross-validated ensemble using 200 learners and the GentleBoost algorithm:

```

a = fitensemble(X,Y,'GentleBoost',200,t,...
    'PredictorNames',VarNames(2:end),'LearnRate',0.1,...
    'CategoricalPredictors',ncat,'kfold',5);
figure;
plot(kfoldLoss(a,'mode','cumulative','lossfun','exponential'));
xlabel('Number of trees');
ylabel('Cross-validated exponential loss');

```



- 9 Inspect the confusion matrix to see which people the ensemble predicts correctly:

```

[Yfit,Sfit] = kfoldPredict(a); %
confusionmat(Y,Yfit,'order',ClassNames)

```

```

ans =
    16    16
    10   113

```

Of the 123 people who live, the ensemble predicts correctly that 113 will live. But for the 32 people who die of hepatitis, the ensemble only predicts correctly that half will die of hepatitis.

10 There are two types of error in the predictions of the ensemble:

- Predicting that the patient lives, but the patient dies
- Predicting that the patient dies, but the patient lives

Suppose you believe that the first error is five times worse than the second. Make a new classification cost matrix that reflects this belief:

```
cost.ClassNames = ClassNames;
cost.ClassificationCosts = [0 5; 1 0];
```

11 Create a new cross-validated ensemble using `cost` as misclassification cost, and inspect the resulting confusion matrix:

```
aC = fitensemble(X,Y,'GentleBoost',200,t,...
    'PredictorNames',VarNames(2:end),'LearnRate',0.1,...
    'CategoricalPredictors',ncat,'kfold',5,...
    'cost',cost);
[YfitC,SfitC] = kfoldPredict(aC);
confusionmat(Y,YfitC,'order',ClassNames)
```

```
ans =
    19    13
     9   114
```

As expected, the new ensemble does a better job classifying the people who die. Somewhat surprisingly, the new ensemble also does a better job classifying the people who live, though the result is not statistically significantly better. The results of the cross validation are random, so this result is simply a statistical fluctuation. The result seems to indicate that the classification of people who live is not very sensitive to the cost.

Classification with Many Categorical Levels

Generally, you cannot use classification with more than 31 levels in any categorical predictor. However, two boosting algorithms can classify data

with many categorical predictor levels and binary responses: `LogitBoost` and `GentleBoost`. For details, see “`LogitBoost`” on page 13-148 and “`GentleBoost`” on page 13-148.

This example uses demographic data from the U.S. Census, available at <http://archive.ics.uci.edu/ml/machine-learning-databases/adult/>. The objective of the researchers who posted the data is predicting whether an individual makes more than \$50,000/year, based on a set of characteristics. You can see details of the data, including predictor names, in the `adult.names` file at the site.

- 1 Load the 'adult.data' file from the UCI Machine Learning Repository:

```
s = urlread(['http://archive.ics.uci.edu/ml/' ...
            'machine-learning-databases/adult/adult.data']);
```

- 2 'adult.data' represents missing data as '?'. Replace instances of missing data with the blank string '':

```
s = strrep(s, '?', '');
```

- 3 Put the data into a MATLAB dataset array:

```
fid = fopen('adult.txt','w');
fwrite(fid,s);
fclose(fid);
clear s;
VarNames = {'age' 'workclass' 'fnlwtg' 'education' 'education_num' ...
            'marital_status' 'occupation' 'relationship' 'race' ...
            'sex' 'capital_gain' 'capital_loss' ...
            'hours_per_week' 'native_country' 'income'};
ds = dataset('file','adult.txt','VarNames',VarNames,...
            'Delimiter',',','ReadVarNames',false,'Format',...
            '%u%s%u%s%u%s%s%s%s%u%u%u%s%s');
cat = ~datasetfun(@isnumeric,ds(:,1:end-1)); % Logical indices
%                                           of categorical variables
catcol = find(cat); % indices of categorical variables
```

- 4 Many predictors in the data are categorical. Convert those fields in the dataset array to nominal:

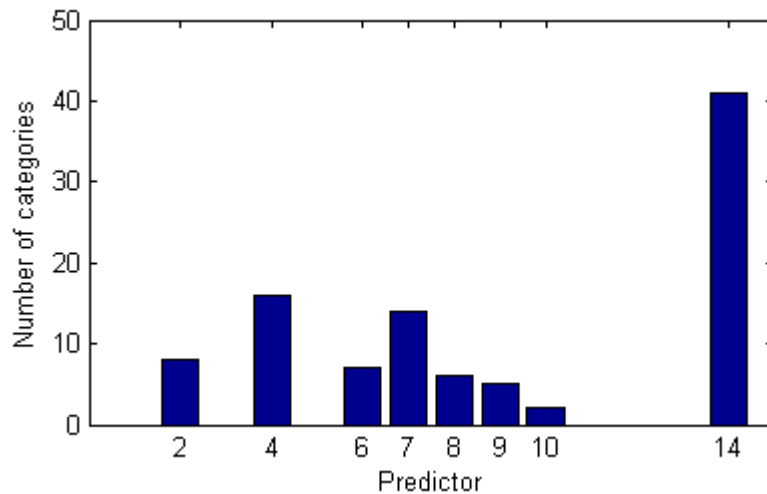

```
ds.workclass = nominal(ds.workclass);
ds.education = nominal(ds.education);
ds.marital_status = nominal(ds.marital_status);
ds.occupation = nominal(ds.occupation);
ds.relationship = nominal(ds.relationship);
ds.race = nominal(ds.race);
ds.sex = nominal(ds.sex);
ds.native_country = nominal(ds.native_country);
ds.income = nominal(ds.income);
```

- 5** Convert the dataset array into numerical variables for fitensemble:

```
X = double(ds(:,1:end-1));
Y = ds.income;
```

- 6** Some variables have many levels. Plot the number of levels of each predictor:

```
ncat = zeros(1,numel(catcol));
for c=1:numel(catcol)
    [~,gn] = grp2idx(X(:,catcol(c)));
    ncat(c) = numel(gn);
end
figure;
bar(catcol,ncat);
xlabel('Predictor');
ylabel('Number of categories');
```



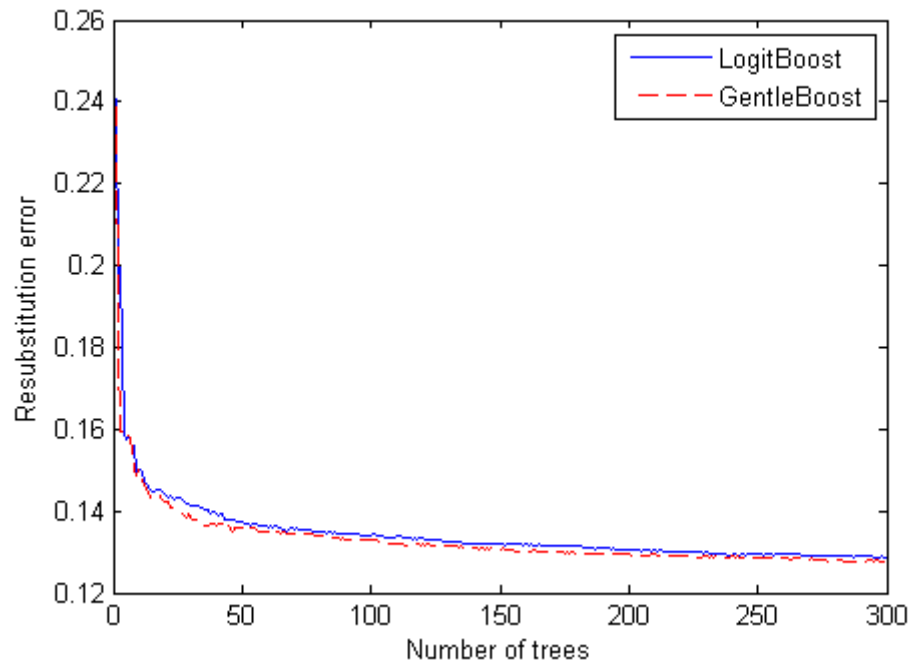
Predictor 14 ('native_country') has more than 40 categorical levels. This is too many levels for any method except LogitBoost and GentleBoost.

7 Create classification ensembles using both LogitBoost and GentleBoost:

```
lb = fitensemble(X,Y,'LogitBoost',300,'Tree','CategoricalPredictors',cat,...
    'PredictorNames',VarNames(1:end-1),'ResponseName','income');
gb = fitensemble(X,Y,'GentleBoost',300,'Tree','CategoricalPredictors',cat,...
    'PredictorNames',VarNames(1:end-1),'ResponseName','income');
```

8 Examine the resubstitution error for the two ensembles:

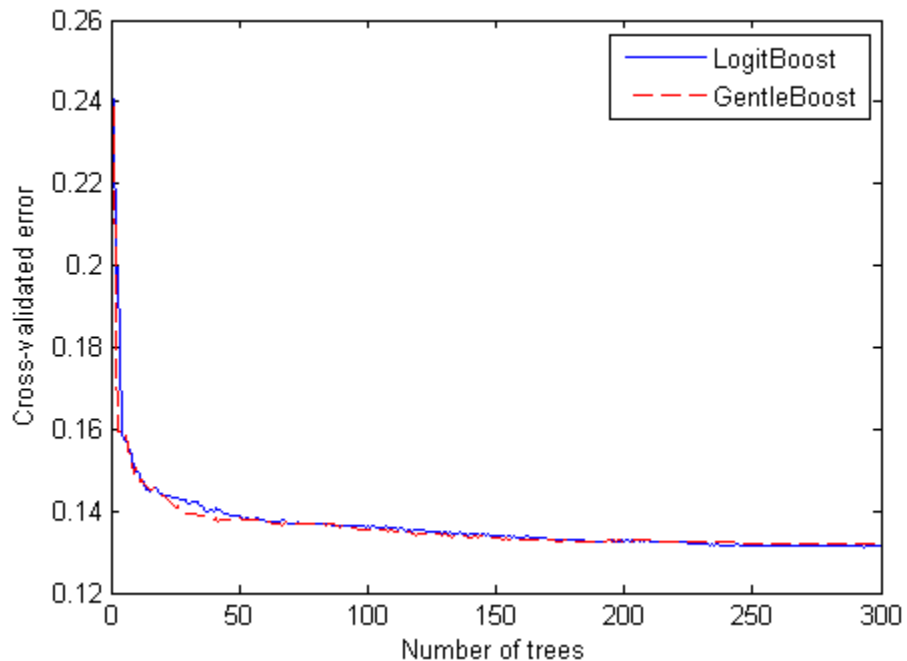
```
figure;
plot(resubLoss(lb,'mode','cumulative'));
hold on
plot(resubLoss(gb,'mode','cumulative'),'r--');
hold off
xlabel('Number of trees');
ylabel('Resubstitution error');
legend('LogitBoost','GentleBoost','Location','NE');
```



The algorithms have similar resubstitution error.

- 9 Estimate the generalization error for the two algorithms by cross validation.

```
lbcv = crossval(lb,'kfold',5);
gbcv = crossval(gb,'kfold',5);
figure;
plot(kfoldLoss(lbcv,'mode','cumulative'));
hold on
plot(kfoldLoss(gbcv,'mode','cumulative'),'r--');
hold off
xlabel('Number of trees');
ylabel('Cross-validated error');
legend('LogitBoost','GentleBoost','Location','NE');
```



The cross-validated loss is nearly the same as the resubstitution error.

Surrogate Splits

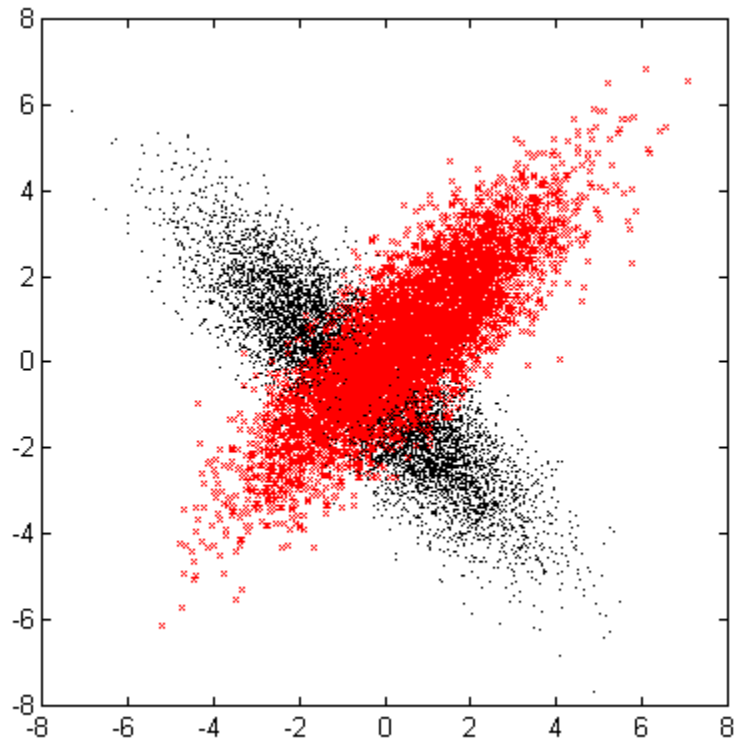
When you have missing data, trees and ensembles of trees give better predictions when they include surrogate splits. Furthermore, estimates of predictor importance are often different with surrogate splits. Eliminating unimportant predictors can save time and memory for predictions, and can make predictions easier to understand.

This example shows the effects of surrogate splits for predictions for data containing missing entries in both training and test sets. There is a redundant predictor in the data, which the surrogate split uses to infer missing values. While the example is artificial, it shows the value of surrogate splits with missing data.

- 1 Generate and plot two different normally distributed populations, one with 5000 members, one with 10,000 members:

```
rng(1,'twister') % for reproducibility
N = 5000;
N1 = 2*N; % number in population 1
N2 = N; % number in population 2
mu1 = [-1 -1]/2; % mean of population 1
mu2 = [1 1]/2; % mean of population 2
S1 = [3    -2.5;...
      -2.5   3]; % variance of population 1
S2 = [3    2.5;...
      2.5   3]; % variance of population 2
X1 = mvnrnd(mu1,S1,N1); % population 1
X2 = mvnrnd(mu2,S2,N2); % population 2
X = [X1; X2]; % total population
Y = ones(N1+N2,1); % label population 1
Y(N1+1:end) = 2; % label population 2

figure
plot(X1(:,1),X1(:,2),'k.','MarkerSize',2)
hold on
plot(X2(:,1),X2(:,2),'rx','MarkerSize',3);
hold off
axis square
```



There is a good deal of overlap between the data points. You cannot expect perfect classification of this data.

- 2** Make a third predictor that is the same as the first component of X :

```
X = [X X(:,1)];
```

- 3** Remove half the values of predictor 1 at random:

```
X(rand(size(X(:,1))) < 0.5,1) = NaN;
```

- 4** Partition the data into a training set and a test set:

```
cv = cvpartition(Y,'holdout',0.3); % 30% test data
```

```
Xtrain = X(training(cv),:);
Ytrain = Y(training(cv));
Xtest = X(test(cv),:);
Ytest = Y(test(cv));
```

- 5** Create two Bag ensembles: one with surrogate splits, one without. First create the template for surrogate splits, then train both ensembles:

```
templS = ClassificationTree.template('surrogate','on');
bag = fitensemble(Xtrain,Ytrain,'Bag',50,'Tree',...
    'type','class','nprint',10);
```

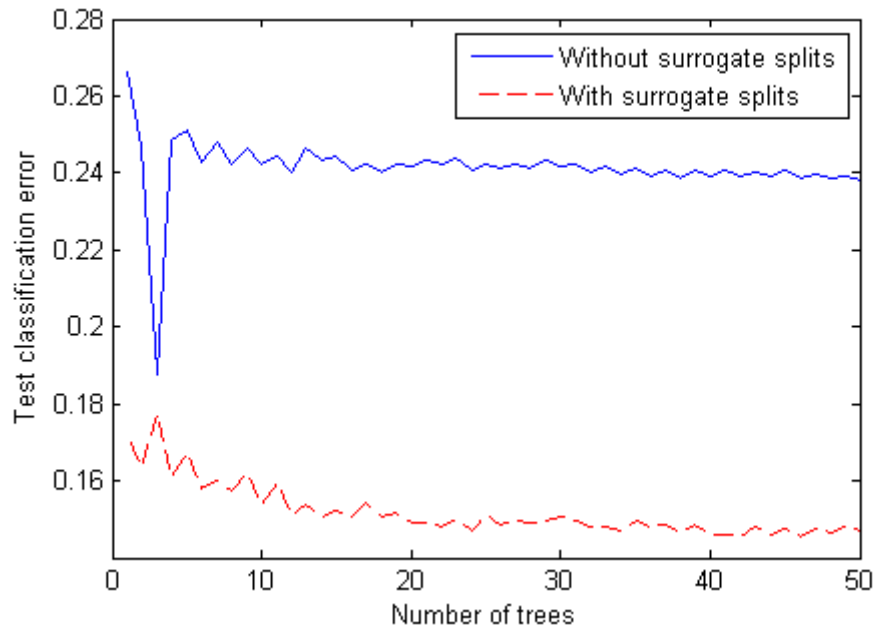
```
Training Bag...
Grown weak learners: 10
Grown weak learners: 20
Grown weak learners: 30
Grown weak learners: 40
Grown weak learners: 50
```

```
bagS = fitensemble(Xtrain,Ytrain,'Bag',50,templS,...
    'type','class','nprint',10);
```

```
Training Bag...
Grown weak learners: 10
Grown weak learners: 20
Grown weak learners: 30
Grown weak learners: 40
Grown weak learners: 50
```

- 6** Examine the accuracy of the two ensembles for predicting the test data:

```
figure
plot(loss(bag,Xtest,Ytest,'mode','cumulative'));
hold on
plot(loss(bagS,Xtest,Ytest,'mode','cumulative'),'r--');
hold off;
legend('Without surrogate splits','With surrogate splits');
xlabel('Number of trees');
ylabel('Test classification error');
```



The ensemble with surrogate splits is obviously more accurate than the ensemble without surrogate splits.

- 7 Check the statistical significance of the difference in results with the McNemar test:

```

Yfit = predict(bag,Xtest);
YfitS = predict(bagS,Xtest);
N10 = sum(Yfit==Ytest & YfitS~=Ytest);
N01 = sum(Yfit~=Ytest & YfitS==Ytest);
mcnemar = (abs(N10-N01) - 1)^2/(N10+N01);
pval = 1 - chi2cdf(mcnemar,1)

pval =
    0

```

The extremely low p -value indicates that the ensemble with surrogate splits is better in a statistically significant manner.

LPBoost and TotalBoost for Small Ensembles

This example shows how to obtain the benefits of the LPBoost and TotalBoost algorithms. These algorithms share two beneficial characteristics:

They are self-terminating, so you don't have to guess how many members to include.

They produce ensembles with some very small weights, so you can safely remove ensemble members.

Caution The algorithms require an Optimization Toolbox license.

Step 1. Load the data.

Load the ionosphere data.

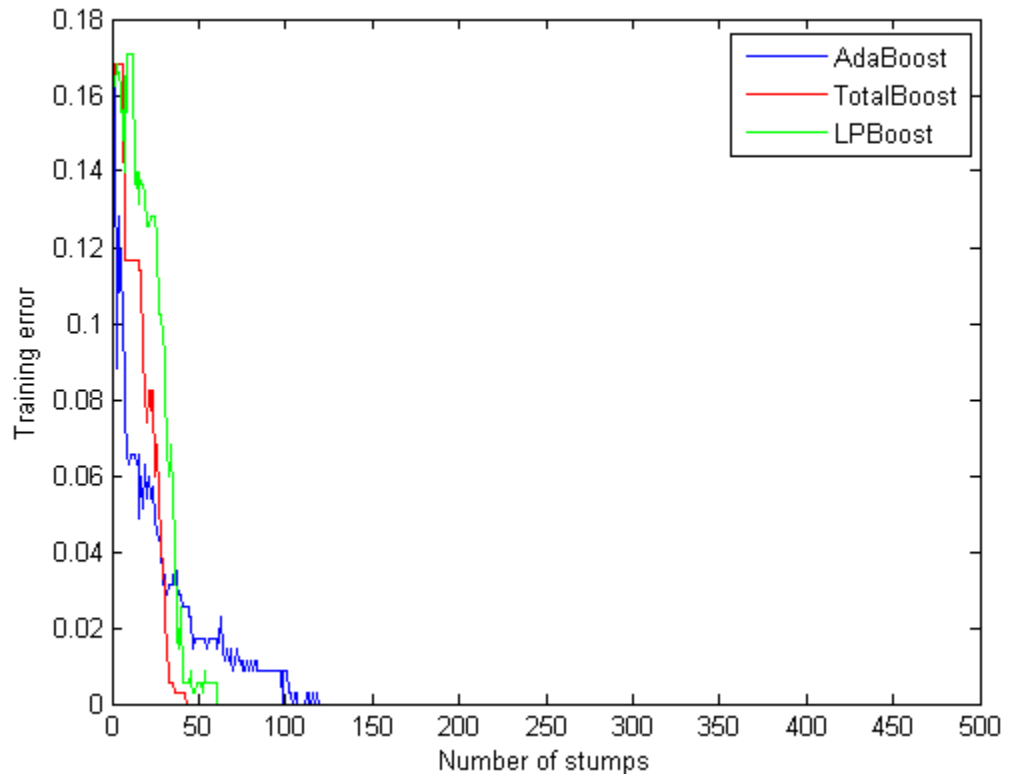
```
load ionosphere
```

Step 2. Create the classification ensembles.

Create ensembles for classifying the ionosphere data using the LPBoost, TotalBoost, and, for comparison, AdaBoostM1 algorithms. It is hard to know how many members to include in an ensemble. For LPBoost and TotalBoost, try using 500. For comparison, also use 500 for AdaBoostM1.

```
rng default % for reproducibility
T = 500;
adaStump = fitensemble(X,Y,'AdaBoostM1',T,'Tree');
totalStump = fitensemble(X,Y,'TotalBoost',T,'Tree');
lpStump = fitensemble(X,Y,'LPBoost',T,'Tree');
figure;
plot(resubLoss(adaStump,'mode','cumulative'));
hold on
plot(resubLoss(totalStump,'mode','cumulative'),'r');
plot(resubLoss(lpStump,'mode','cumulative'),'g');
hold off
xlabel('Number of stumps');
ylabel('Training error');
```

```
legend('AdaBoost','TotalBoost','LPBoost','Location','NE');
```



All three algorithms achieve perfect prediction on the training data after a while. Examine the number of members in all three ensembles.

```
[adaStump.NTrained totalStump.NTrained lpStump.NTrained]
```

```
ans =
```

```
500    52    67
```

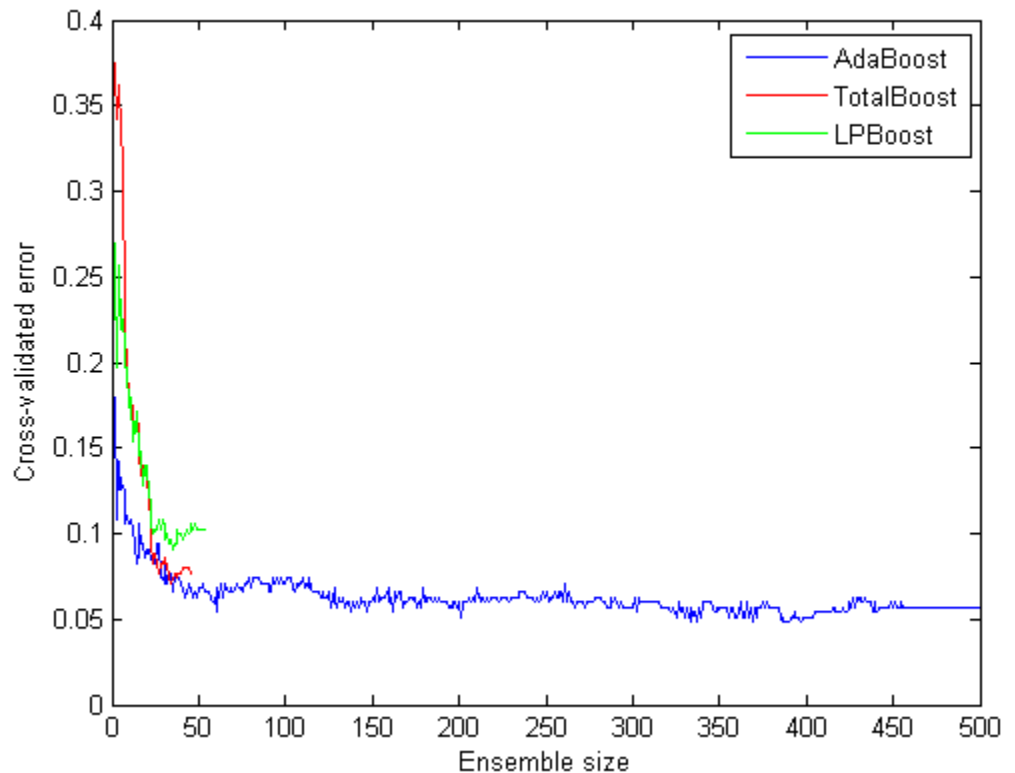
AdaBoostM1 trained all 500 members. The other two algorithms stopped training early.

Step 3. Cross validate the ensembles.

Cross validate the ensembles to better determine ensemble accuracy.

```
cvlp = crossval(lpStump,'kfold',5);
cvtotal = crossval(totalStump,'kfold',5);
cvada = crossval(adaStump,'kfold',5);

figure;
plot(kfoldLoss(cvada,'mode','cumulative'));
hold on
plot(kfoldLoss(cvtotal,'mode','cumulative'),'r');
plot(kfoldLoss(cvlp,'mode','cumulative'),'g');
hold off
xlabel('Ensemble size');
ylabel('Cross-validated error');
legend('AdaBoost','TotalBoost','LPBoost','Location','NE');
```



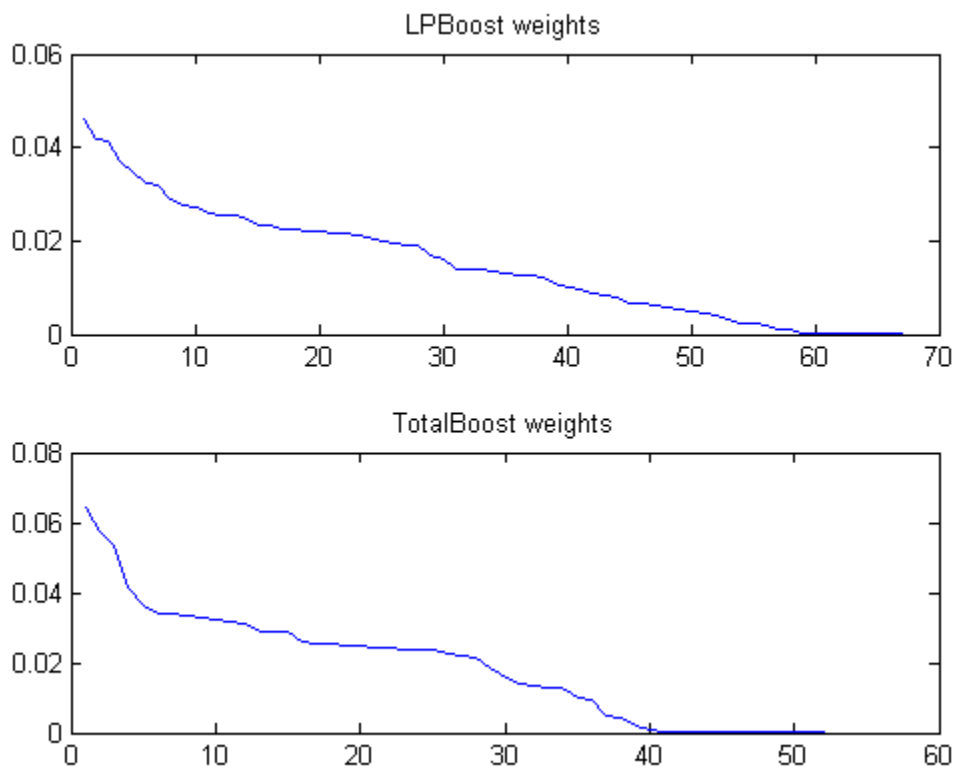
It appears that each boosting algorithms achieves 10% or lower loss with 50 ensemble members, and AdaBoostM1 achieves near 6% error with 150 or more ensemble members.

Step 4. Compact and remove ensemble members.

To reduce the ensemble sizes, compact them, and then use the `removeLearners` method. The question is, how many learners should you remove? The cross-validated loss curves give you one measure. For another, examine the learner weights for LPBoost and TotalBoost after compacting.

```
cada = compact(adaStump);
c1p = compact(lpStump);
```

```
ctotal = compact(totalStump);  
  
figure  
subplot(2,1,1)  
plot(clp.TrainedWeights)  
title('LPBoost weights')  
subplot(2,1,2)  
plot(ctotal.TrainedWeights)  
title('TotalBoost weights')
```



Both LPBoost and TotalBoost show clear points where the ensemble member weights become negligible.

Remove the unimportant ensemble members.

```
cada = removeLearners(cada,150:cada.NTrained);  
clp = removeLearners(clp,60:clp.NTrained);  
ctotal = removeLearners(ctotal,40:ctotal.NTrained);
```

Check that removing these learners does not affect ensemble accuracy on the training data.

```
[loss(cada,X,Y) loss(clp,X,Y) loss(ctotal,X,Y)]
```

```
ans =  
  
    0    0    0
```

Check the resulting compact ensemble sizes.

```
s(1) = whos('cada');  
s(2) = whos('clp');  
s(3) = whos('ctotal');  
s.bytes
```

```
ans =  
  
    605605
```

```
ans =  
  
    241375
```

```
ans =  
  
    160435
```

The sizes of the compact ensembles are approximately proportional to the number of members in each.

Ensemble Regularization

Regularization is a process of choosing fewer weak learners for an ensemble in a way that does not diminish predictive performance. Currently you can regularize regression ensembles. (You can also regularize a discriminant analysis classifier in a non-ensemble context; see “Regularize a Discriminant Analysis Classifier” on page 12-22.)

The `regularize` method finds an optimal set of learner weights a_t that minimize

$$\sum_{n=1}^N w_n g \left(\left(\sum_{t=1}^T \alpha_t h_t(x_n) \right), y_n \right) + \lambda \sum_{t=1}^T |\alpha_t|.$$

Here

- $\lambda \geq 0$ is a parameter you provide, called the lasso parameter.
- h_t is a weak learner in the ensemble trained on N observations with predictors x_n , responses y_n , and weights w_n .
- $g(f,y) = (f - y)^2$ is the squared error.

The ensemble is regularized on the same (x_n, y_n, w_n) data used for training, so

$$\sum_{n=1}^N w_n g \left(\left(\sum_{t=1}^T \alpha_t h_t(x_n) \right), y_n \right)$$

is the ensemble resubstitution error. The error is measured by mean squared error (MSE).

If you use $\lambda = 0$, `regularize` finds the weak learner weights by minimizing the resubstitution MSE. Ensembles tend to overtrain. In other words, the resubstitution error is typically smaller than the true generalization error. By making the resubstitution error even smaller, you are likely to make the ensemble accuracy worse instead of improving it. On the other hand, positive values of λ push the magnitude of the α_t coefficients to 0. This often improves the generalization error. Of course, if you choose λ too large, all the optimal coefficients are 0, and the ensemble does not have any accuracy. Usually you can find an optimal range for λ in which the accuracy of the regularized ensemble is better or comparable to that of the full ensemble without regularization.

A nice feature of lasso regularization is its ability to drive the optimized coefficients precisely to 0. If a learner's weight α_t is 0, this learner can be

excluded from the regularized ensemble. In the end, you get an ensemble with improved accuracy and fewer learners.

Example: Regularizing a Regression Ensemble

This example uses data for predicting the insurance risk of a car based on its many attributes.

- 1** Load the `imports-85` data into the MATLAB workspace:

```
load imports-85;
```

- 2** Look at a description of the data to find the categorical variables and predictor names:

Description

```
Description =  
1985 Auto Imports Database from the UCI repository  
http://archive.ics.uci.edu/ml/machine-learning-databases/autos/imports-85.names  
Variables have been reordered to place variables with numeric values (referred  
to as "continuous" on the UCI site) to the left and categorical values to the  
right. Specifically, variables 1:16 are: symboling, normalized-losses,  
wheel-base, length, width, height, curb-weight, engine-size, bore, stroke,  
compression-ratio, horsepower, peak-rpm, city-mpg, highway-mpg, and price.  
Variables 17:26 are: make, fuel-type, aspiration, num-of-doors, body-style,  
drive-wheels, engine-location, engine-type, num-of-cylinders, and fuel-system.
```

The objective of this process is to predict the “symboling,” the first variable in the data, from the other predictors. “symboling” is an integer from -3 (good insurance risk) to 3 (poor insurance risk). You could use a classification ensemble to predict this risk instead of a regression ensemble. As stated in “Steps in Supervised Learning (Machine Learning)” on page 13-2, when you have a choice between regression and classification, you should try regression first. Furthermore, this example is to show regularization, which currently works only for regression.

- 3** Prepare the data for ensemble fitting:


```

Y = X(:,1);
X(:,1) = [];
VarNames = {'normalized-losses' 'wheel-base' 'length' 'width' 'height' ...
            'curb-weight' 'engine-size' 'bore' 'stroke' 'compression-ratio' ...
            'horsepower' 'peak-rpm' 'city-mpg' 'highway-mpg' 'price' 'make' ...
            'fuel-type' 'aspiration' 'num-of-doors' 'body-style' 'drive-wheels' ...
            'engine-location' 'engine-type' 'num-of-cylinders' 'fuel-system'};
catidx = 16:25; % indices of categorical predictors

```

4 Create a regression ensemble from the data using 300 default trees:

```

ls = fitensemble(X,Y,'LSBoost',300,'Tree','LearnRate',0.1,...
                'PredictorNames',VarNames,'ResponseName','symboling',...
                'CategoricalPredictors',catidx)

```

```
ls =
```

```

classreg.learning.regr.RegressionEnsemble:
    PredictorNames: {1x25 cell}
    CategoricalPredictors: [16 17 18 19 20 21 22 23 24 25]
    ResponseName: 'symboling'
    ResponseTransform: 'none'
    NObservations: 205
    NTrained: 300
    Method: 'LSBoost'
    LearnerNames: {'Tree'}
    ReasonForTermination: [1x77 char]
    FitInfo: [300x1 double]
    FitInfoDescription: [2x83 char]
    Regularization: []

```

The final line, `Regularization`, is empty (`[]`). To regularize the ensemble, you have to use the `regularize` method.

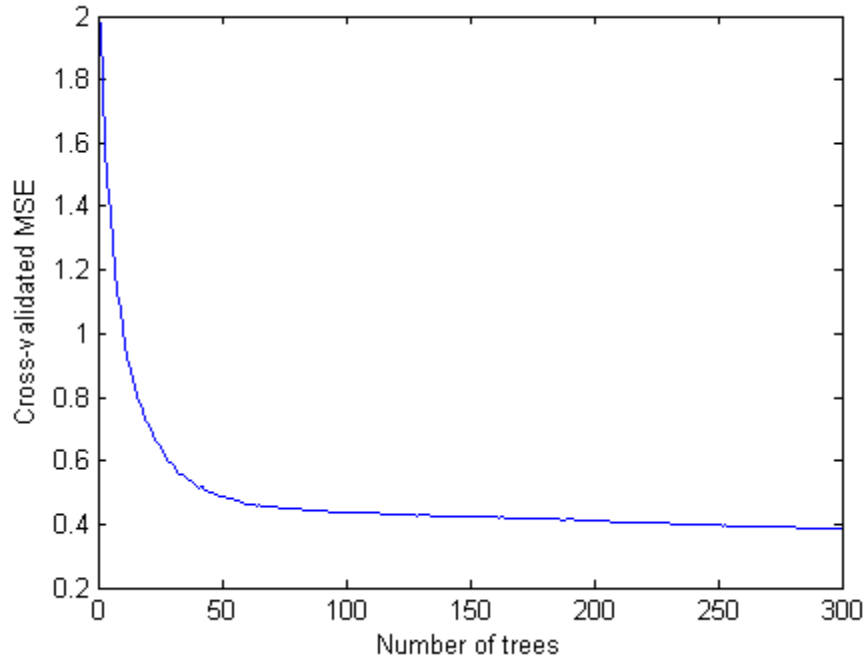
5 Cross validate the ensemble, and inspect its loss curve.

```

cv = crossval(ls,'kfold',5);
figure;
plot(kfoldLoss(cv,'mode','cumulative'));

```

```
xlabel('Number of trees');
ylabel('Cross-validated MSE');
```



It appears you might obtain satisfactory performance from a smaller ensemble, perhaps one containing from 50 to 100 trees.

- 6 Call the `regularize` method to try to find trees that you can remove from the ensemble. By default, `regularize` examines 10 values of the lasso (`Lambda`) parameter spaced exponentially.

```
ls = regularize(ls)
```

```
ls =
```

```
classreg.learning.regr.RegressionEnsemble:
```

```
    PredictorNames: {1x25 cell}
```

```
    CategoricalPredictors: [16 17 18 19 20 21 22 23 24 25]
```

```

        ResponseName: 'symboling'
    ResponseTransform: 'none'
    NObservations: 205
    NTrained: 300
    Method: 'LSBoost'
    LearnerNames: {'Tree'}
    ReasonForTermination: [1x77 char]
        FitInfo: [300x1 double]
    FitInfoDescription: [2x83 char]
    Regularization: [1x1 struct]

```

The Regularization property is no longer empty.

- 7 Plot the resubstitution mean-squared error (MSE) and number of learners with nonzero weights against the lasso parameter. Separately plot the value at $\text{Lambda}=0$. Use a logarithmic scale because the values of Lambda are exponentially spaced.

```

figure;
semilogx(ls.Regularization.Lambda,ls.Regularization.ResubstitutionMSE);
line([1e-3 1e-3],[ls.Regularization.ResubstitutionMSE(1) ...
    ls.Regularization.ResubstitutionMSE(1)],...
    'marker','x','markersize',12,'color','b');
r0 = resubLoss(ls);
line([ls.Regularization.Lambda(2) ls.Regularization.Lambda(end)],...
    [r0 r0],'color','r','LineStyle','--');
xlabel('Lambda');
ylabel('Resubstitution MSE');
annotation('textbox',[0.5 0.22 0.5 0.05],'String','unregularized ensemble',...
    'color','r','FontSize',14,'LineStyle','none');

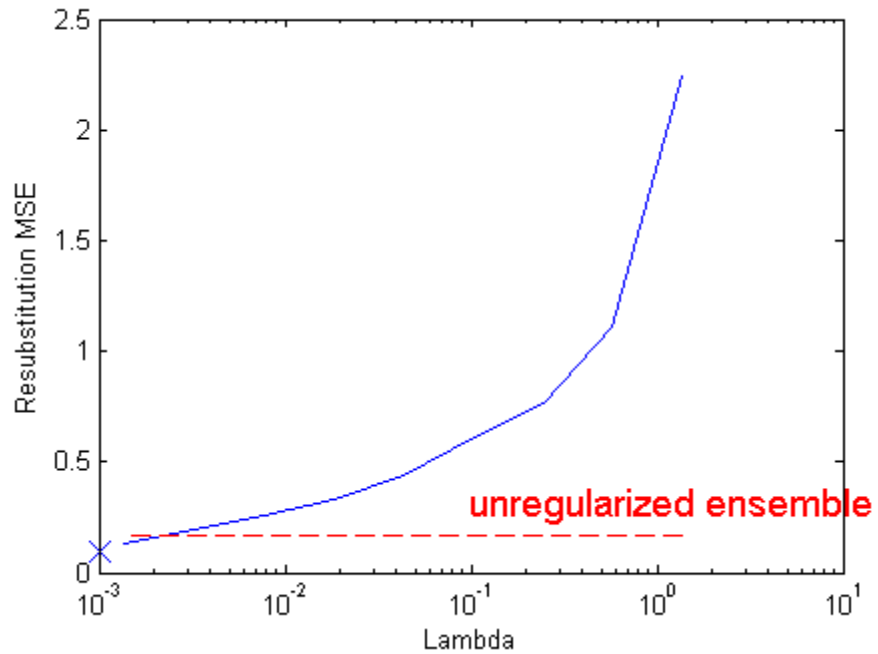
```

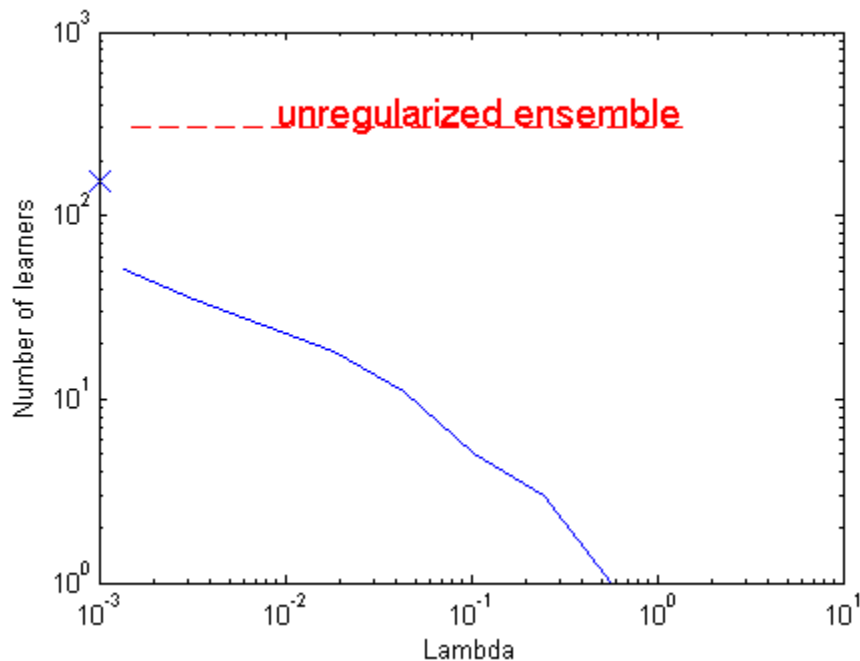
```

figure;
loglog(ls.Regularization.Lambda,sum(ls.Regularization.TrainedWeights>0,1));
line([1e-3 1e-3],...
    [sum(ls.Regularization.TrainedWeights(:,1)>0) ...
    sum(ls.Regularization.TrainedWeights(:,1)>0)],...
    'marker','x','markersize',12,'color','b');
line([ls.Regularization.Lambda(2) ls.Regularization.Lambda(end)],...
    [ls.NTrained ls.NTrained],...

```

```
'color','r','LineStyle','--');  
xlabel('Lambda');  
ylabel('Number of learners');  
annotation('textbox',[0.3 0.8 0.5 0.05],'String','unregularized ensemble',...  
           'color','r','FontSize',14,'LineStyle','none');
```





- 8** The resubstitution MSE values are likely to be overly optimistic. To obtain more reliable estimates of the error associated with various values of Lambda, cross validate the ensemble using `cvshrink`. Plot the resulting cross-validation loss (MSE) and number of learners against Lambda.

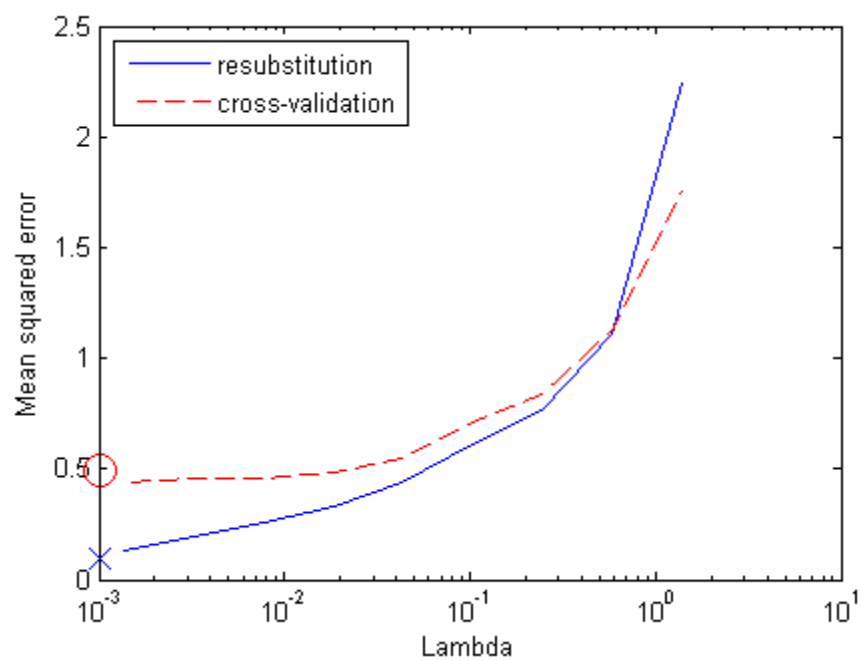
```
rng(0,'Twister') % for reproducibility
[mse,nlearn] = cvshrink(ls,'lambda',ls.Regularization.Lambda,'kfold',5);

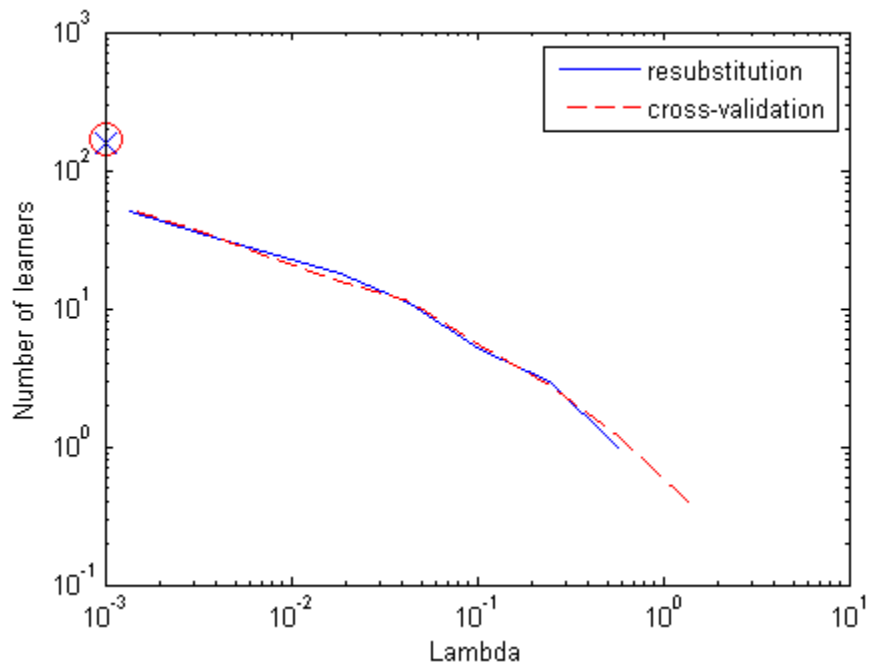
figure;
semilogx(ls.Regularization.Lambda,ls.Regularization.ResubstitutionMSE);
hold;
semilogx(ls.Regularization.Lambda,mse,'r--');
hold off;
xlabel('Lambda');
ylabel('Mean squared error');
legend('resubstitution','cross-validation','Location','NW');
```

```
line([1e-3 1e-3],[ls.Regularization.ResubstitutionMSE(1) ...
    ls.Regularization.ResubstitutionMSE(1)],...
    'marker','x','markersize',12,'color','b');
line([1e-3 1e-3],[mse(1) mse(1)],'marker','o',...
    'markersize',12,'color','r','LineStyle','--');

figure;
loglog(ls.Regularization.Lambda,sum(ls.Regularization.TrainedWeights>0,1));
hold;
loglog(ls.Regularization.Lambda,nlearn,'r--');
hold off;
xlabel('Lambda');
ylabel('Number of learners');
legend('resubstitution','cross-validation','Location','NE');
line([1e-3 1e-3],...
    [sum(ls.Regularization.TrainedWeights(:,1)>0) ...
    sum(ls.Regularization.TrainedWeights(:,1)>0)],...
    'marker','x','markersize',12,'color','b');
line([1e-3 1e-3],[nlearn(1) nlearn(1)],'marker','o',...
```

```
'markersize',12,'color','r','LineStyle','--');
```





Examining the cross-validated error shows that the cross-validation MSE is almost flat for Lambda up to a bit over $1e-2$.

- 9 Examine `ls.Regularization.Lambda` to find the highest value that gives MSE in the flat region (up to a bit over $1e-2$):

```
jj = 1:length(ls.Regularization.Lambda);
[jj;ls.Regularization.Lambda]
```

ans =

Columns 1 through 6

1.0000	2.0000	3.0000	4.0000	5.0000	6.0000
0	0.0014	0.0033	0.0077	0.0183	0.0435

Columns 7 through 10


```

7.0000    8.0000    9.0000   10.0000
0.1031    0.2446    0.5800    1.3754

```

Element 5 of `ls.Regularization.Lambda` has value 0.0183, the largest in the flat range.

- 10** Reduce the ensemble size using the `shrink` method. `shrink` returns a compact ensemble with no training data. The generalization error for the new compact ensemble was already estimated by cross validation in `mse(5)`.

```

cmp = shrink(ls,'weightcolumn',5)

cmp =

classreg.learning.regr.CompactRegressionEnsemble:
    PredictorNames: {1x25 cell}
    CategoricalPredictors: [16 17 18 19 20 21 22 23 24 25]
    ResponseName: 'symboling'
    ResponseTransform: 'none'
    NTrained: 18

```

There are only 18 trees in the new ensemble, notably reduced from the 300 in `ls`.

- 11** Compare the sizes of the ensembles:

```

sz(1) = whos('cmp'); sz(2) = whos('ls');
[sz(1).bytes sz(2).bytes]

ans =
    162270    2791024

```

The reduced ensemble is about 6% the size of the original.

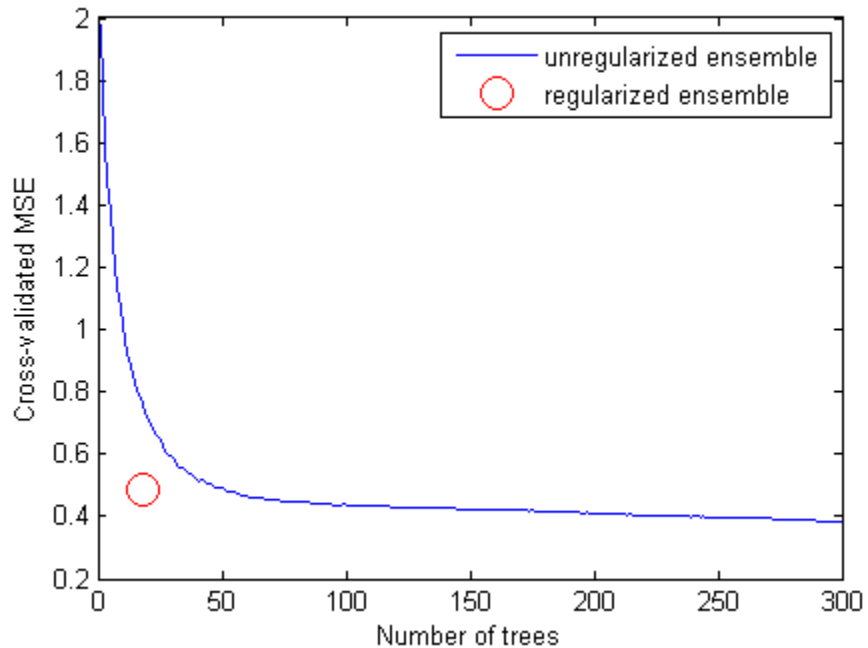
- 12** Compare the MSE of the reduced ensemble to that of the original ensemble:

```

figure;
plot(kfoldLoss(cv,'mode','cumulative'));
hold on
plot(cmp.NTrained,mse(5),'ro','MarkerSize',12);
xlabel('Number of trees');

```

```
ylabel('Cross-validated MSE');  
legend('unregularized ensemble','regularized ensemble',...  
      'Location','NE');  
hold off
```



The reduced ensemble gives low loss while using many fewer trees.

Tuning RobustBoost

The RobustBoost algorithm can make good classification predictions even when the training data has noise. However, the default RobustBoost parameters can produce an ensemble that does not predict well. This example shows one way of tuning the parameters for better predictive accuracy.

Note RobustBoost requires an Optimization Toolbox license.

- 1 Generate data with label noise. This example has twenty uniform random numbers per observation, and classifies the observation as 1 if the sum of the first five numbers exceeds 2.5 (so is larger than average), and 0 otherwise:

```
rng(0,'twister') % for reproducibility
Xtrain = rand(2000,20);
Ytrain = sum(Xtrain(:,1:5),2) > 2.5;
```

- 2 To add noise, randomly switch 10% of the classifications:

```
idx = randsample(2000,200);
Ytrain(idx) = ~Ytrain(idx);
```

- 3 Create an ensemble with AdaBoostM1 for comparison purposes:

```
ada = fitensemble(Xtrain,Ytrain,'AdaBoostM1',...
    300,'Tree','LearnRate',0.1);
```

- 4 Create an ensemble with RobustBoost. Because the data has 10% incorrect classification, perhaps an error goal of 15% is reasonable.

```
rb1 = fitensemble(Xtrain,Ytrain,'RobustBoost',300,...
    'Tree','RobustErrorGoal',0.15,'RobustMaxMargin',1);
```

- 5 Try setting a high value of the error goal, 0.6. You get an error:

```
rb2 = fitensemble(Xtrain,Ytrain,'RobustBoost',300,'Tree','RobustErrorGoal',0.6)
```

Error using RobustBoost>RobustBoost.RobustBoost

For the chosen values of 'RobustMaxMargin' and 'RobustMarginSigma', you must set 'RobustErrorGoal' to a value between 0 and 0.5.

- 6 Create an ensemble with an error goal in the allowed range, 0.4:

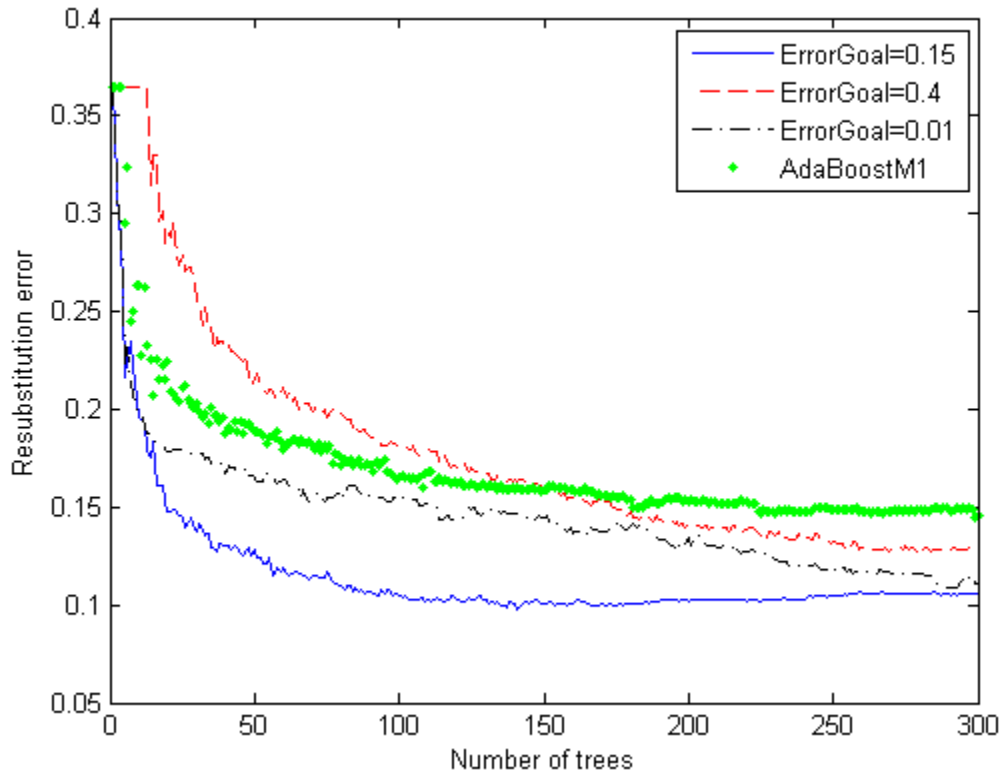
```
rb2 = fitensemble(Xtrain,Ytrain,'RobustBoost',300,...
    'Tree','RobustErrorGoal',0.4);
```

- 7 Create an ensemble with very optimistic error goal, 0.01:

```
rb3 = fitensemble(Xtrain,Ytrain,'RobustBoost',300,...
    'Tree','RobustErrorGoal',0.01);
```

8 Compare the resubstitution error of the four ensembles:

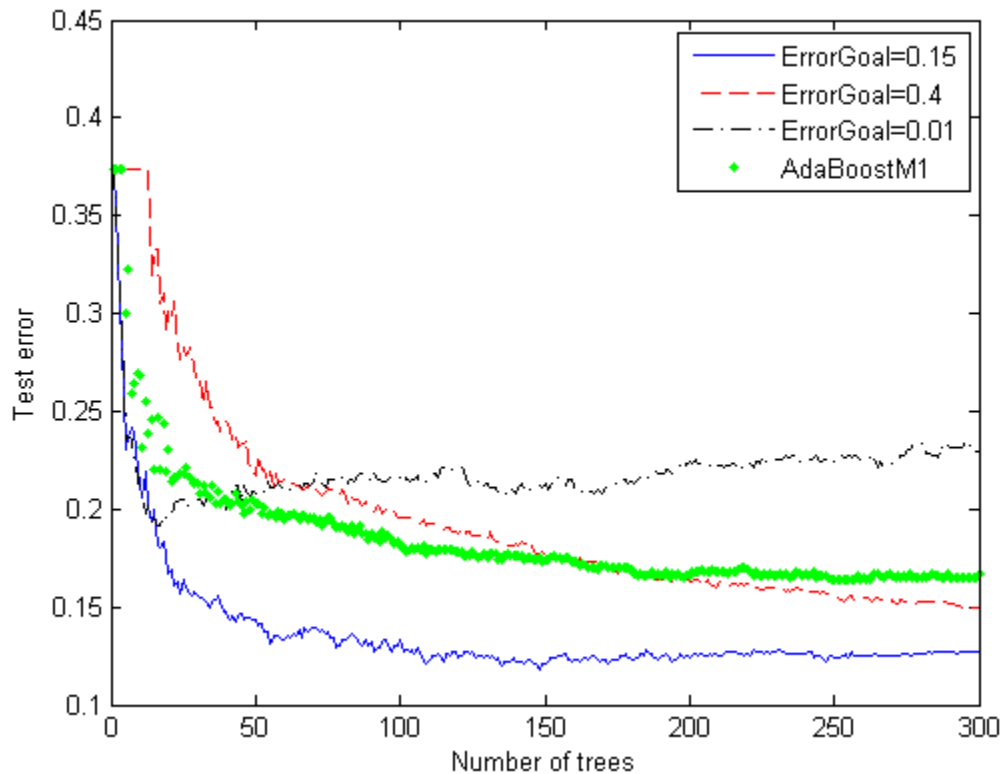
```
figure
plot(resubLoss(rb1,'mode','cumulative'));
hold on
plot(resubLoss(rb2,'mode','cumulative'),'r--');
plot(resubLoss(rb3,'mode','cumulative'),'k-.');
plot(resubLoss(ada,'mode','cumulative'),'g. ');
hold off;
xlabel('Number of trees');
ylabel('Resubstitution error');
legend('ErrorGoal=0.15','ErrorGoal=0.4','ErrorGoal=0.01',...
      'AdaBoostM1','Location','NE');
```



All the RobustBoost curves show lower resubstitution error than the AdaBoostM1 curve. The error goal of 0.15 curve shows the lowest resubstitution error over most of the range. However, its error is rising in the latter half of the plot, while the other curves are still descending.

- 9 Generate test data to see the predictive power of the ensembles. Test the four ensembles:

```
Xtest = rand(2000,20);
Ytest = sum(Xtest(:,1:5),2) > 2.5;
idx = randsample(2000,200);
Ytest(idx) = ~Ytest(idx);
figure;
plot(loss(rb1,Xtest,Ytest,'mode','cumulative'));
hold on
plot(loss(rb2,Xtest,Ytest,'mode','cumulative'),'r--');
plot(loss(rb3,Xtest,Ytest,'mode','cumulative'),'k-.');
plot(loss(ada,Xtest,Ytest,'mode','cumulative'),'g. ');
hold off;
xlabel('Number of trees');
ylabel('Test error');
legend('ErrorGoal=0.15','ErrorGoal=0.4','ErrorGoal=0.01',...
      'AdaBoostM1','Location','NE');
```



The error curve for error goal 0.15 is lowest (best) in the plotted range. The curve for error goal 0.4 seems to be converging to a similar value for a large number of trees, but more slowly. AdaBoostM1 has higher error than the curve for error goal 0.15. The curve for the too-optimistic error goal 0.01 remains substantially higher (worse) than the other algorithms for most of the plotted range.

Random Subspace Classification

This example shows how to use a random subspace ensemble to increase the accuracy of classification. It also shows how to use cross validation to

determine good parameters for both the weak learner template and the ensemble.

1. Load the data.

Load the ionosphere data. This data has 351 binary responses to 34 predictors.

```
load ionosphere;
[N,D] = size(X)

N =
    351

D =
    34

resp = unique(Y)

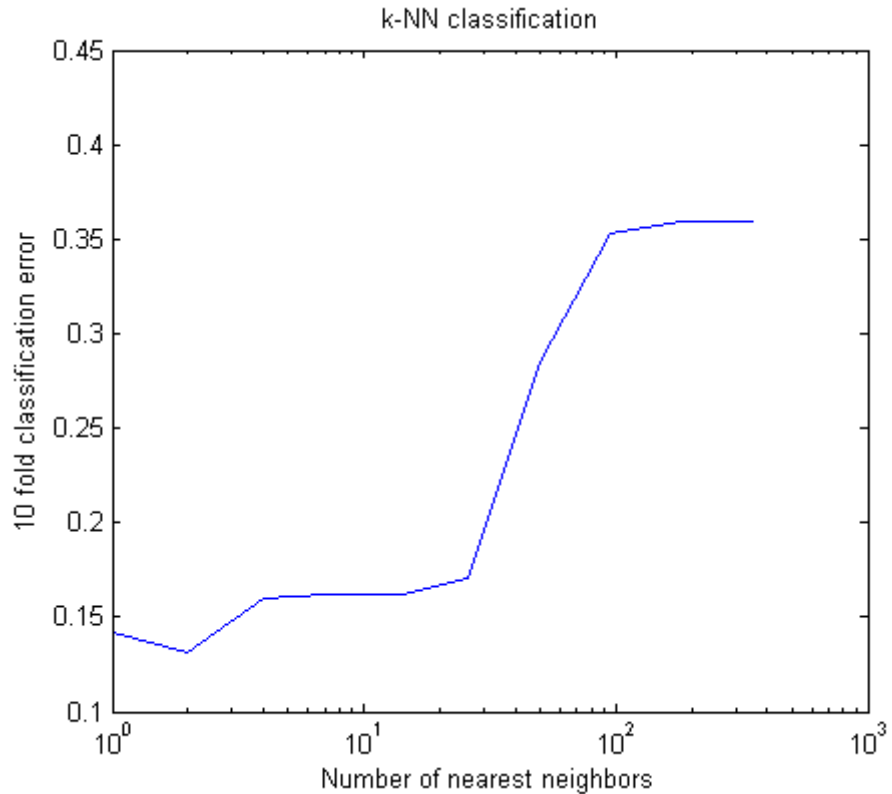
resp =
    'b'
    'g'
```

2. Choose the number of nearest neighbors.

Find a good choice for k , the number of nearest neighbors in the classifier, by cross validation. Choose the number of neighbors approximately evenly spaced on a logarithmic scale.

```
rng(8000,'twister') % for reproducibility
K = round(logspace(0,log10(N),10)); % number of neighbors
cvloss = zeros(numel(K),1);
for k=1:numel(K)
    knn = ClassificationKNN.fit(X,Y,...
        'NumNeighbors',K(k),'crossval','on');
    cvloss(k) = kfoldLoss(knn);
end
figure; % plot the accuracy versus k
semilogx(K,cvloss);
xlabel('Number of nearest neighbors');
ylabel('10 fold classification error');
```

```
title('k-NN classification');
```



The lowest cross-validation error occurs for $k = 2$.

3. Create the ensembles.

Create ensembles for 2-nearest neighbor classification with various numbers of dimensions, and examine the cross-validated loss of the resulting ensembles.

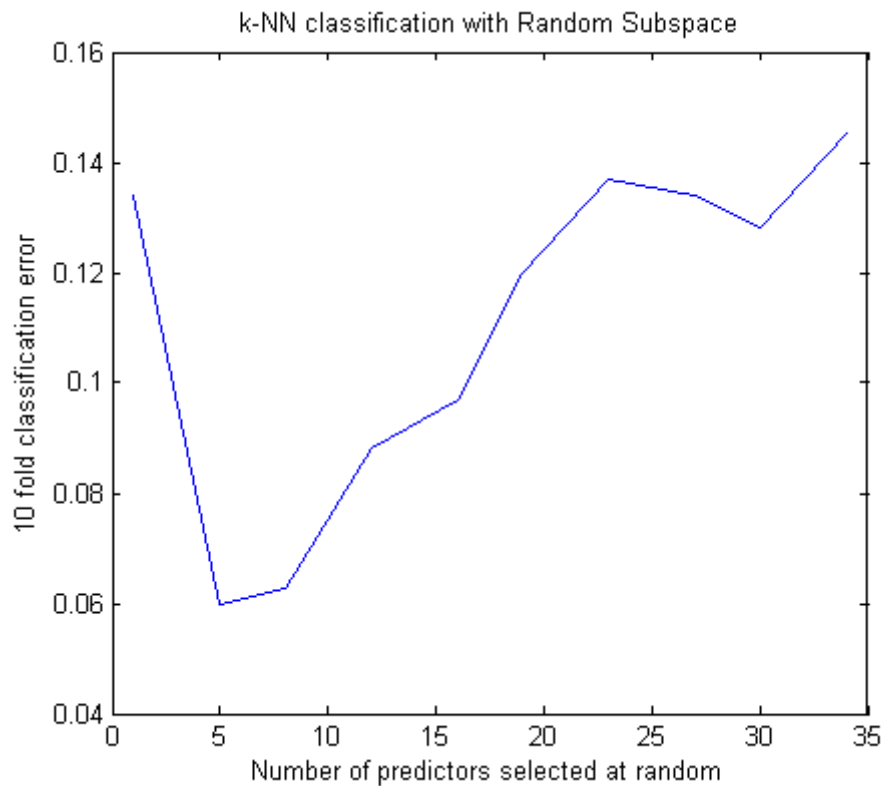
This step takes a long time. To keep track of the progress, print a message as each dimension finishes.

```
NPredToSample = round(linspace(1,D,10)); % linear spacing of dimensions
```



```
cvloss = zeros(numel(NPredToSample),1);
learner = ClassificationKNN.template('NumNeighbors',2);
for npred=1:numel(NPredToSample)
    subspace = fitensemble(X,Y,'subspace',200,learner,...
        'npredtosample',NPredToSample(npred),'crossval','on');
    cvloss(npred) = kfoldLoss(subspace);
    fprintf('Random Subspace %i done.\n',npred);
end
figure; % plot the accuracy versus dimension
plot(NPredToSample,cvloss);
xlabel('Number of predictors selected at random');
ylabel('10 fold classification error');
title('k-NN classification with Random Subspace');
```

```
Random Subspace 1 done.
Random Subspace 2 done.
Random Subspace 3 done.
Random Subspace 4 done.
Random Subspace 5 done.
Random Subspace 6 done.
Random Subspace 7 done.
Random Subspace 8 done.
Random Subspace 9 done.
Random Subspace 10 done.
```



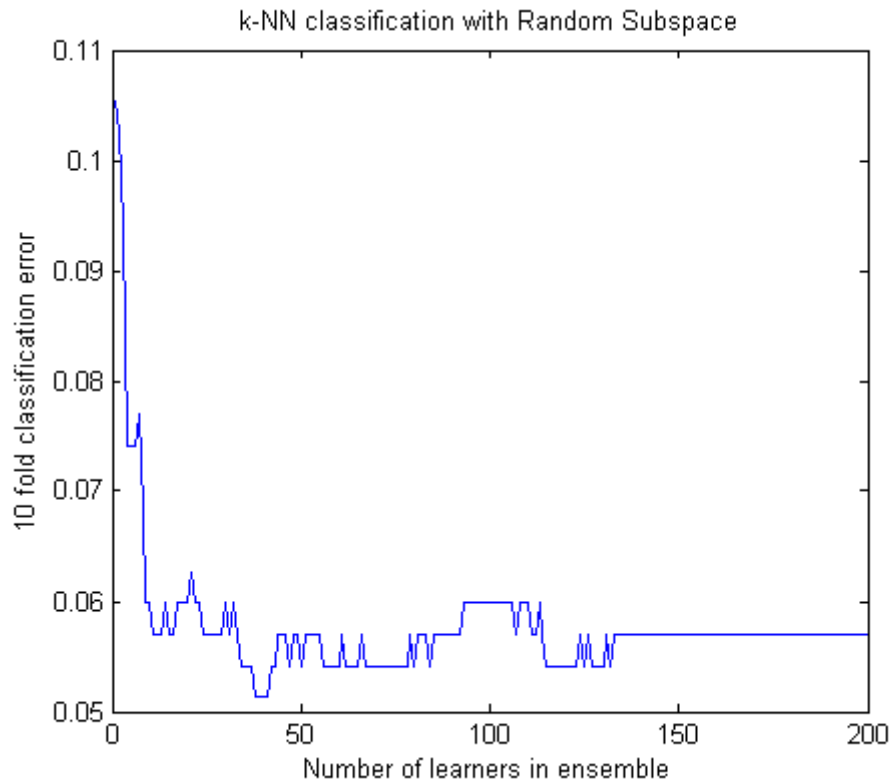
The ensemble with five predictors per learner has the lowest cross-validated error. The error rate, about 0.06, is about half the amount for the individual learners, which was over 0.10.

4. Find a good ensemble size.

Find the smallest number of learners in the ensemble that still give good classification.

```
ens = fitensemble(X,Y,'subspace',200,learner,...
    'npredtosample',5,'crossval','on');
figure; % plot the accuracy versus number in ensemble
plot(kfoldLoss(ens,'mode','cumulative'))
xlabel('Number of learners in ensemble');
```

```
ylabel('10 fold classification error');  
title('k-NN classification with Random Subspace');
```



There seems to be no advantage in an ensemble with more than 150 or so learners. It is not clear whether there is any advantage with more than 50 learners. It is possible that 25 learners gives good predictions.

5. Create a final ensemble.

Construct a final ensemble with 50 learners. Compact the ensemble and see if the compacted version saves an appreciable amount of memory.

```
ens = fitensemble(X,Y,'subspace',50,learner,...  
    'npretdosample',5);
```

```
cens = compact(ens);
s1 = whos('ens');s2 = whos('cens');
[s1.bytes s2.bytes] % si.bytes = size in bytes

ans =
    2317803    2087370
```

The compact ensemble is about 10% smaller than the full ensemble. Both give the same predictions.

TreeBagger Examples

TreeBagger ensembles have more functionality than those constructed with `fitensemble`; see `TreeBagger Features Not in fitensemble` on page 13-146. Also, some property and method names differ from their `fitensemble` counterparts. This section contains examples of workflow for regression and classification that use this extra TreeBagger functionality.

Workflow Example: Regression of Insurance Risk Rating for Car Imports with TreeBagger

In this example, use a database of 1985 car imports with 205 observations, 25 input variables, and one response variable, insurance risk rating, or “symboling.” The first 15 variables are numeric and the last 10 are categorical. The symboling index takes integer values from -3 to 3 .

- 1 Load the dataset and split it into predictor and response arrays:

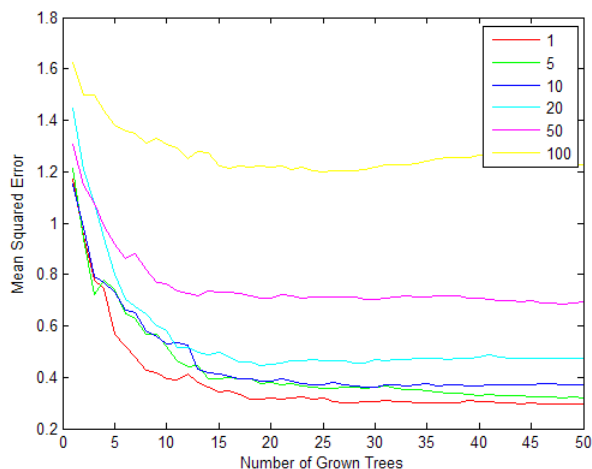
```
load imports-85;
Y = X(:,1);
X = X(:,2:end);
```

- 2 Because bagging uses randomized data drawings, its exact outcome depends on the initial random seed. To reproduce the exact results in this example, use the random stream settings:

```
rng(1945,'twister')
```

Finding the Optimal Leaf Size. For regression, the general rule is to set leaf size to 5 and select one third of input features for decision splits at random. In the following step, verify the optimal leaf size by comparing mean-squared errors obtained by regression for various leaf sizes. `oobError` computes MSE versus the number of grown trees. You must set `oobpred` to 'on' to obtain out-of-bag predictions later.

```
leaf = [1 5 10 20 50 100];
col = 'rgbcmy';
figure(1);
for i=1:length(leaf)
    b = TreeBagger(50,X,Y,'method','r','oobpred','on',...
        'cat',16:25,'minleaf',leaf(i));
    plot(oobError(b),col(i));
    hold on;
end
xlabel('Number of Grown Trees');
ylabel('Mean Squared Error');
legend({'1' '5' '10' '20' '50' '100'},'Location','NorthEast');
hold off;
```



The red (leaf size 1) curve gives the lowest MSE values.

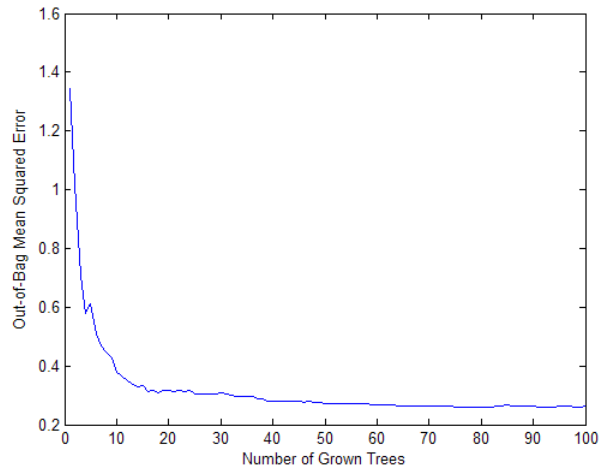
Estimating Feature Importance.

- 1 In practical applications, you typically grow ensembles with hundreds of trees. Only 50 trees were used in “Finding the Optimal Leaf Size” on page 13-121 for faster processing. Now that you have estimated the optimal leaf size, grow a larger ensemble with 100 trees and use it for estimation of feature importance:

```
b = TreeBagger(100,X,Y,'method','r','oobvarimp','on',...  
'cat',16:25,'minleaf',1);
```

- 2 Inspect the error curve again to make sure nothing went wrong during training:

```
figure(2);  
plot(oobError(b));  
xlabel('Number of Grown Trees');  
ylabel('Out-of-Bag Mean Squared Error');
```



Prediction ability should depend more on important features and less on unimportant features. You can use this idea to measure feature importance.

For each feature, you can permute the values of this feature across all of the observations in the data set and measure how much worse the mean-squared

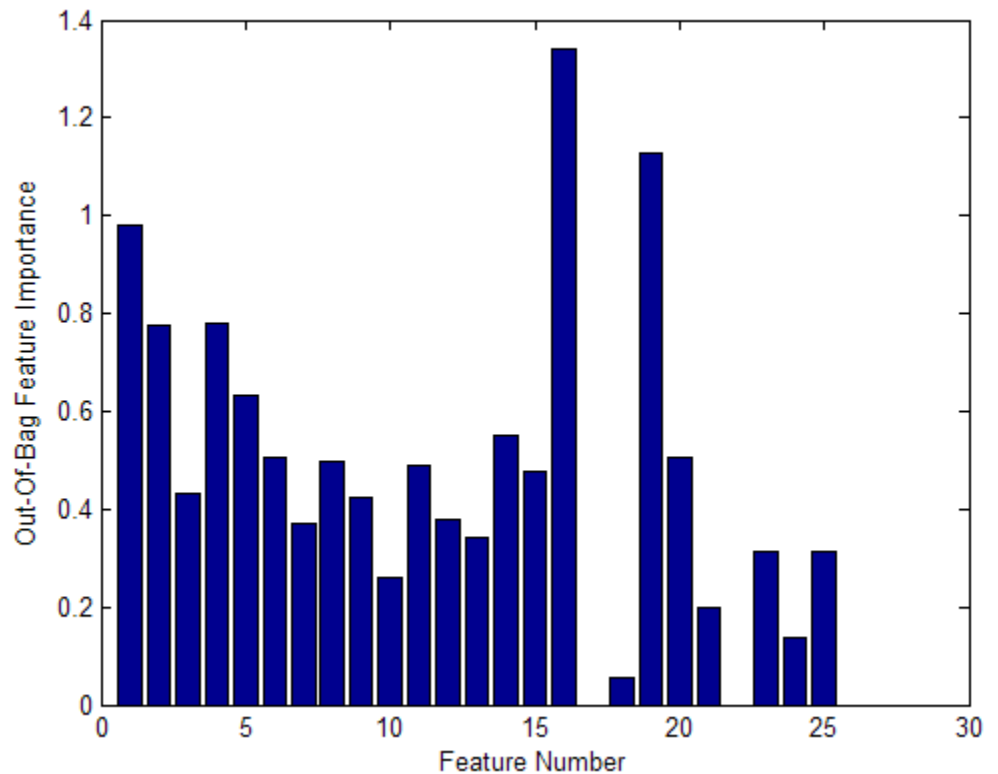
error (MSE) becomes after the permutation. You can repeat this for each feature.

- 1 Using the following code, plot the increase in MSE due to permuting out-of-bag observations across each input variable. The `OOBPermutedVarDeltaError` array stores the increase in MSE averaged over all trees in the ensemble and divided by the standard deviation taken over the trees, for each variable. The larger this value, the more important the variable. Imposing an arbitrary cutoff at 0.65, you can select the five most important features.

```
figure(3);
bar(b.OOBPermutedVarDeltaError);
xlabel('Feature Number');
ylabel('Out-Of-Bag Feature Importance');
idxvar = find(b.OOBPermutedVarDeltaError>0.65)

idxvar =

     1     2     4    16    19
```



- 2** The `OOBIndices` property of `TreeBagger` tracks which observations are out of bag for what trees. Using this property, you can monitor the fraction of observations in the training data that are in bag for all trees. The curve starts at approximately $2/3$, the fraction of unique observations selected by one bootstrap replica, and goes down to 0 at approximately 10 trees.

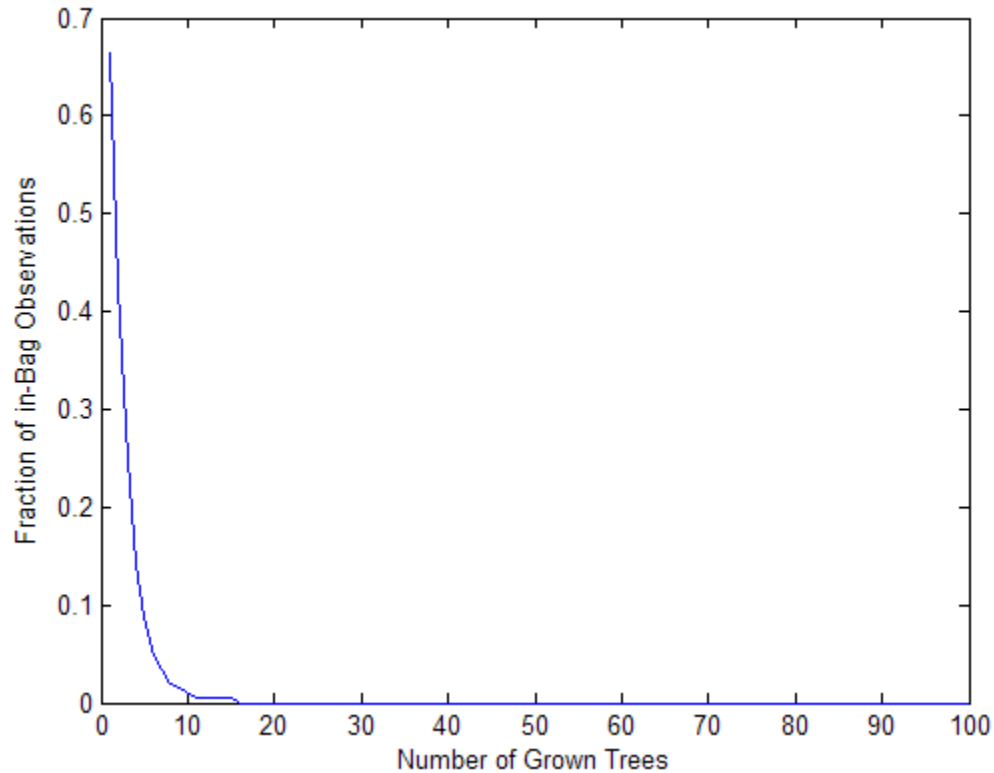
```

finbag = zeros(1,b.NTrees);
for t=1:b.NTrees
    finbag(t) = sum(all(~b.OOBIndices(:,1:t),2));
end
finbag = finbag / size(X,1);
figure(4);
plot(finbag);

```



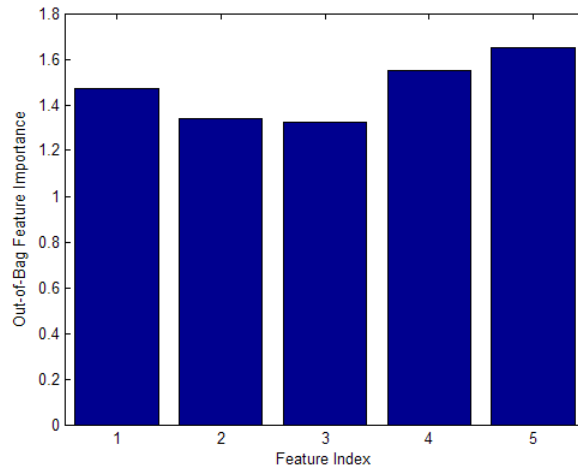
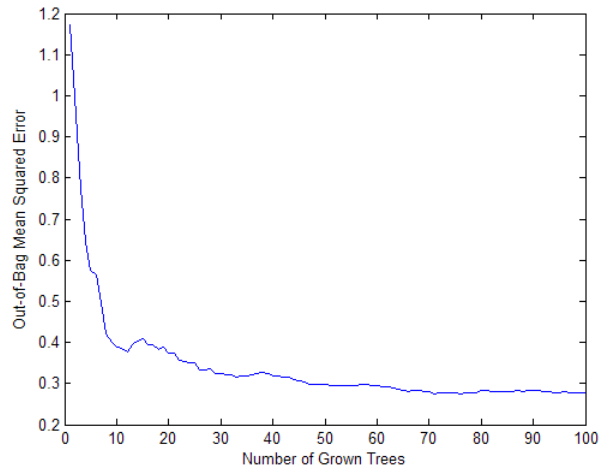
```
xlabel('Number of Grown Trees');  
ylabel('Fraction of in-Bag Observations');
```



Growing Trees on a Reduced Set of Features. Using just the five most powerful features selected in “Estimating Feature Importance” on page 13-122, determine if it is possible to obtain a similar predictive power. To begin, grow 100 trees on these features only. The first three of the five selected features are numeric and the last two are categorical.

```
b5v = TreeBagger(100,X(:,idxvar),Y,'method','r',...  
'oobvarimp','on','cat',4:5,'minleaf',1);  
figure(5);  
plot(oobError(b5v));
```

```
xlabel('Number of Grown Trees');  
ylabel('Out-of-Bag Mean Squared Error');  
figure(6);  
bar(b5v.00BPermutedVarDeltaError);  
xlabel('Feature Index');  
ylabel('Out-of-Bag Feature Importance');
```



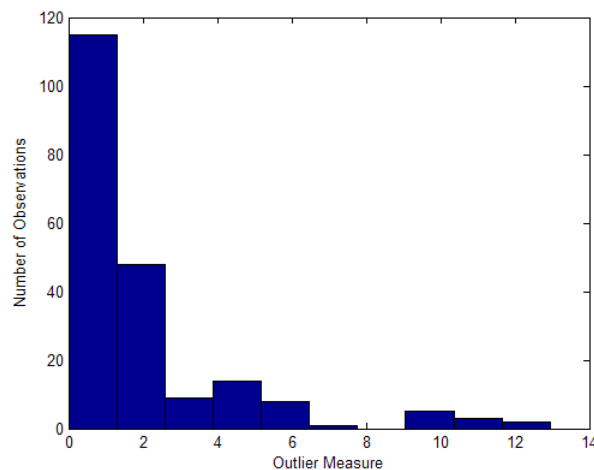
These five most powerful features give the same MSE as the full set, and the ensemble trained on the reduced set ranks these features similarly to each other. Features 1 and 2 from the reduced set perhaps could be removed without a significant loss in the predictive power.

Finding Outliers. To find outliers in the training data, compute the proximity matrix using `fillProximities`:

```
b5v = fillProximities(b5v);
```

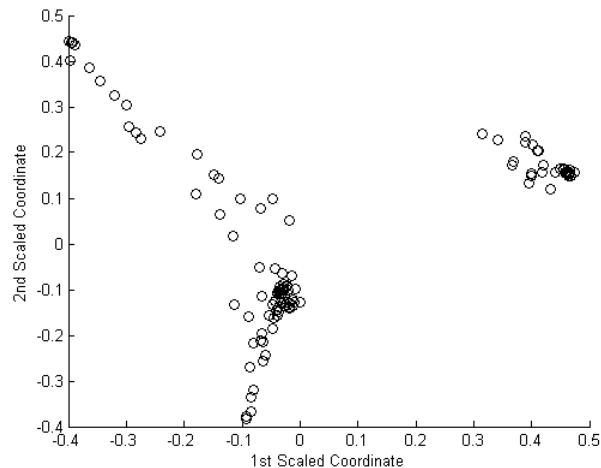
The method normalizes this measure by subtracting the mean outlier measure for the entire sample, taking the magnitude of this difference and dividing the result by the median absolute deviation for the entire sample:

```
figure(7);  
hist(b5v.OutlierMeasure);  
xlabel('Outlier Measure');  
ylabel('Number of Observations');
```



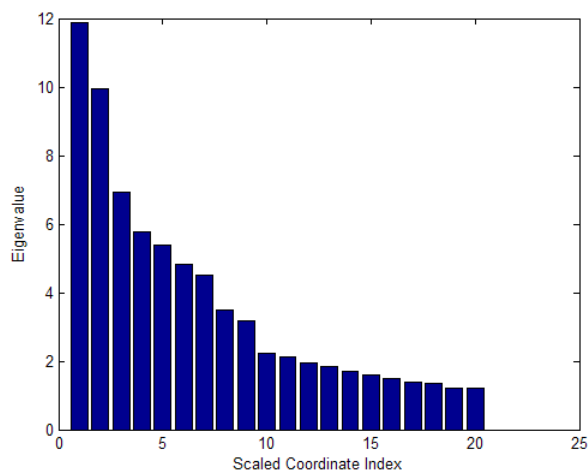
Discovering Clusters in the Data. By applying multidimensional scaling to the computed matrix of proximities, you can inspect the structure of the input data and look for possible clusters of observations. The `mdsProx` method returns scaled coordinates and eigenvalues for the computed proximity matrix. If run with the `colors` option, this method makes a scatter plot of two scaled coordinates, first and second by default.

```
figure(8);  
[~,e] = mdsProx(b5v,'colors','k');  
xlabel('1st Scaled Coordinate');  
ylabel('2nd Scaled Coordinate');
```



Assess the relative importance of the scaled axes by plotting the first 20 eigenvalues:

```
figure(9);  
bar(e(1:20));  
xlabel('Scaled Coordinate Index');  
ylabel('Eigenvalue');
```



Saving the Ensemble Configuration for Future Use. To use the trained ensemble for predicting the response on unseen data, store the ensemble to disk and retrieve it later. If you do not want to compute predictions for out-of-bag data or reuse training data in any other way, there is no need to store the ensemble object itself. Saving the compact version of the ensemble would be enough in this case. Extract the compact object from the ensemble:

```
c = compact(b5v)
```

```
c =
```

```
Ensemble with 100 decision trees:
```

```
Method:          regression
```

```
Nvars:          5
```

This object can be now saved in a *.mat file as usual.

Workflow Example: Classifying Radar Returns for Ionosphere Data with TreeBagger

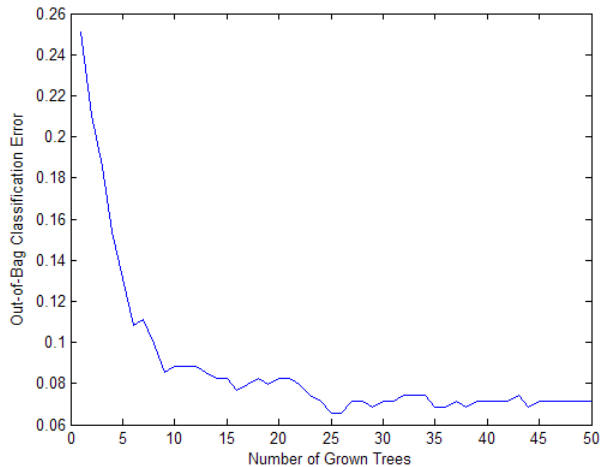
You can also use ensembles of decision trees for classification. For this example, use ionosphere data with 351 observations and 34 real-valued predictors. The response variable is categorical with two levels:

- 'g' for good radar returns
- 'b' for bad radar returns

The goal is to predict good or bad returns using a set of 34 measurements. The workflow resembles that for “Workflow Example: Regression of Insurance Risk Rating for Car Imports with TreeBagger” on page 13-120.

- 1 Fix the initial random seed, grow 50 trees, inspect how the ensemble error changes with accumulation of trees, and estimate feature importance. For classification, it is best to set the minimal leaf size to 1 and select the square root of the total number of features for each decision split at random. These are the default settings for a TreeBagger used for classification.

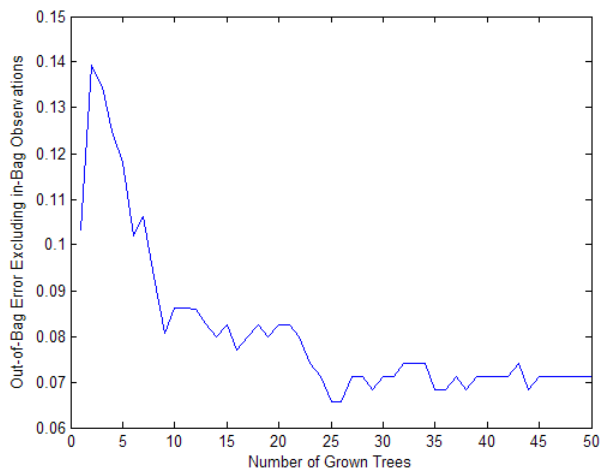
```
load ionosphere;
rng(1945, 'twister')
b = TreeBagger(50,X,Y, 'oobvarimp', 'on');
figure(10);
plot(oobError(b));
xlabel('Number of Grown Trees');
ylabel('Out-of-Bag Classification Error');
```



- 2 The method trains ensembles with few trees on observations that are in bag for all trees. For such observations, it is impossible to compute the true

out-of-bag prediction, and `TreeBagger` returns the most probable class for classification and the sample mean for regression. You can change the default value returned for in-bag observations using the `DefaultYfit` property. If you set the default value to an empty string for classification, the method excludes in-bag observations from computation of the out-of-bag error. In this case, the curve is more variable when the number of trees is small, either because some observations are never out of bag (and are therefore excluded) or because their predictions are based on few trees.

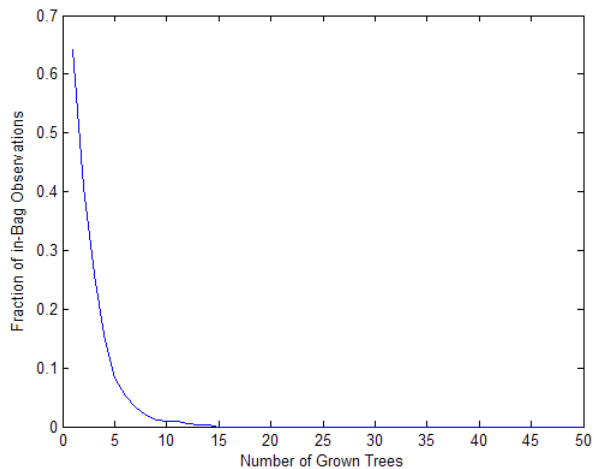
```
b.DefaultYfit = '';
figure(11);
plot(oobError(b));
xlabel('Number of Grown Trees');
ylabel('Out-of-Bag Error Excluding in-Bag Observations');
```



- The `OOBIndices` property of `TreeBagger` tracks which observations are out of bag for what trees. Using this property, you can monitor the fraction of observations in the training data that are in bag for all trees. The curve starts at approximately $2/3$, the fraction of unique observations selected by one bootstrap replica, and goes down to 0 at approximately 10 trees.

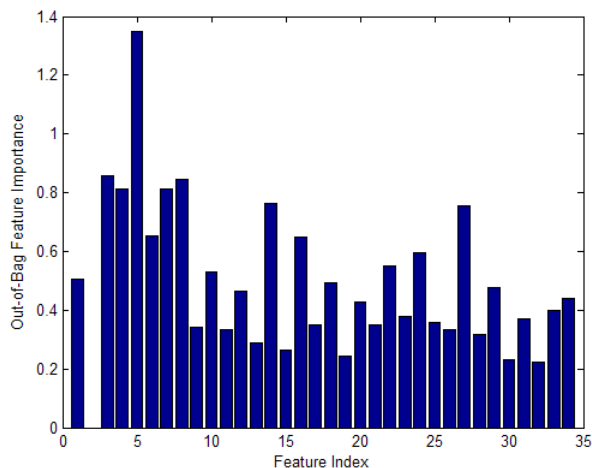
```
finbag = zeros(1,b.NTrees);
for t=1:b.NTrees
    finbag(t) = sum(all(~b.OOBIndices(:,1:t),2));
```

```
end  
finbag = finbag / size(X,1);  
figure(12);  
plot(finbag);  
xlabel('Number of Grown Trees');  
ylabel('Fraction of in-Bag Observations');
```



4 Estimate feature importance:

```
figure(13);  
bar(b.OOBPermutedVarDeltaError);  
xlabel('Feature Index');  
ylabel('Out-of-Bag Feature Importance');  
idxvar = find(b.OOBPermutedVarDeltaError>0.8)  
  
idxvar =  
  
3 4 5 7 8
```

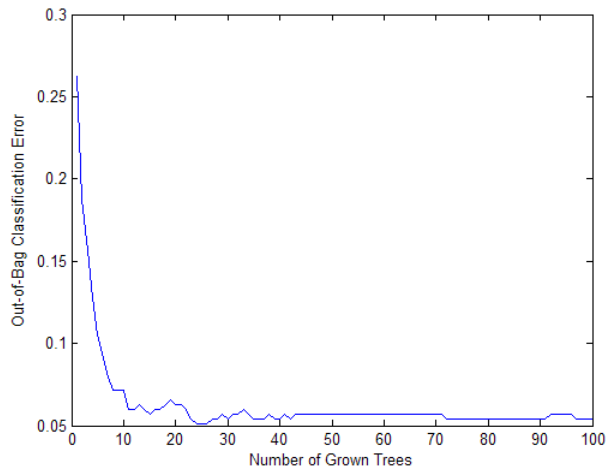



- 5** Having selected the five most important features, grow a larger ensemble on the reduced feature set. Save time by not permuting out-of-bag observations to obtain new estimates of feature importance for the reduced feature set (set `oobvarimp` to `'off'`). You would still be interested in obtaining out-of-bag estimates of classification error (set `oobpred` to `'on'`).

```

b5v = TreeBagger(100,X(:,idxvar),Y,'oobpred','on');
figure(14);
plot(oobError(b5v));
xlabel('Number of Grown Trees');
ylabel('Out-of-Bag Classification Error');

```

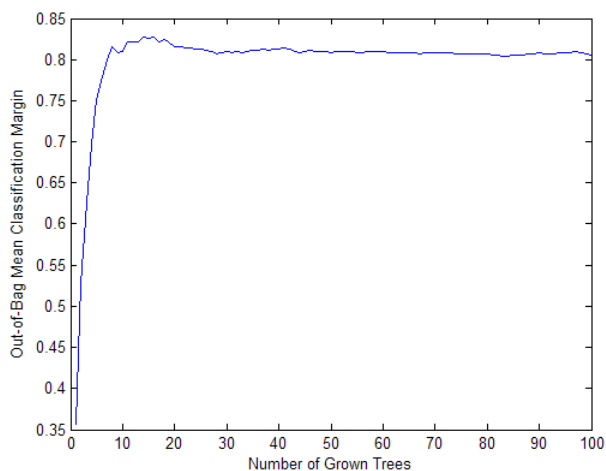


- 6 For classification ensembles, in addition to classification error (fraction of misclassified observations), you can also monitor the average classification margin. For each observation, the *margin* is defined as the difference between the score for the true class and the maximal score for other classes predicted by this tree. The cumulative classification margin uses the scores averaged over all trees and the mean cumulative classification margin is the cumulative margin averaged over all observations. The `oobMeanMargin` method with the `'mode'` argument set to `'cumulative'` (default) shows how the mean cumulative margin changes as the ensemble grows: every new element in the returned array represents the cumulative margin obtained by including a new tree in the ensemble. If training is successful, you would expect to see a gradual increase in the mean classification margin.

For decision trees, a classification score is the probability of observing an instance of this class in this tree leaf. For example, if the leaf of a grown decision tree has five 'good' and three 'bad' training observations in it, the scores returned by this decision tree for any observation fallen on this leaf are $5/8$ for the 'good' class and $3/8$ for the 'bad' class. These probabilities are called 'scores' for consistency with other classifiers that might not have an obvious interpretation for numeric values of returned predictions.

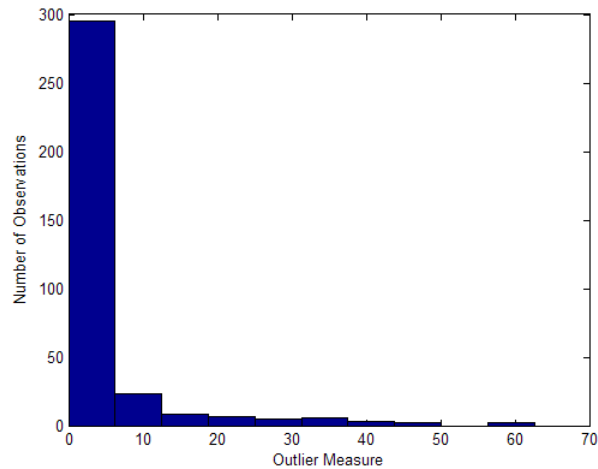
```
figure(15);  
plot(oobMeanMargin(b5v));
```

```
xlabel('Number of Grown Trees');  
ylabel('Out-of-Bag Mean Classification Margin');
```



- 7 Compute the matrix of proximities and look at the distribution of outlier measures. Unlike regression, outlier measures for classification ensembles are computed within each class separately.

```
b5v = fillProximities(b5v);  
figure(16);  
hist(b5v.OutlierMeasure);  
xlabel('Outlier Measure');  
ylabel('Number of Observations');
```



8 All extreme outliers for this dataset come from the 'good' class:

```
b5v.Y(b5v.OutlierMeasure>40)
```

ans =

```
'g'
'g'
'g'
'g'
'g'
```

9 As for regression, you can plot scaled coordinates, displaying the two classes in different colors using the `colors` argument of `mdsProx`. This argument takes a string in which every character represents a color. To find the order of classes used by the ensemble, look at the `ClassNames` property:

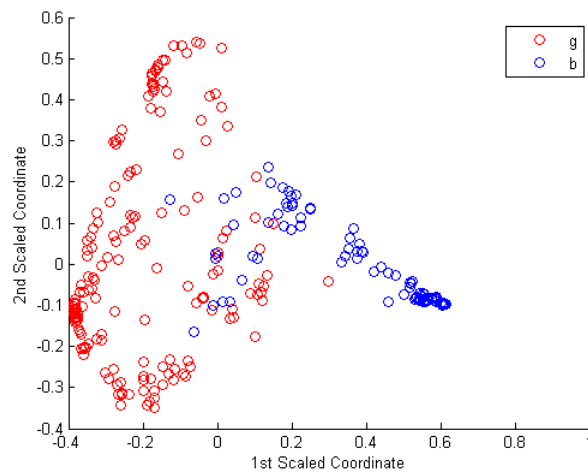
```
b5v.ClassNames
```

ans =

```
'g'
'b'
```

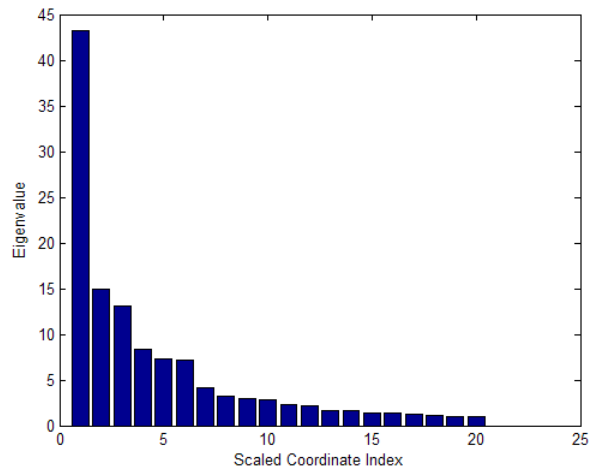
The 'good' class is first and the 'bad' class is second. Display scaled coordinates using red for 'good' and blue for 'bad' observations:

```
figure(17);  
[S,e] = mdsProx(b5v,'colors','rb');  
xlabel('1st Scaled Coordinate');  
ylabel('2nd Scaled Coordinate');
```



- 10** Plot the first 20 eigenvalues obtained by scaling. The first eigenvalue in this case clearly dominates and the first scaled coordinate is most important.

```
figure(18);  
bar(e(1:20));  
xlabel('Scaled Coordinate Index');  
ylabel('Eigenvalue');
```



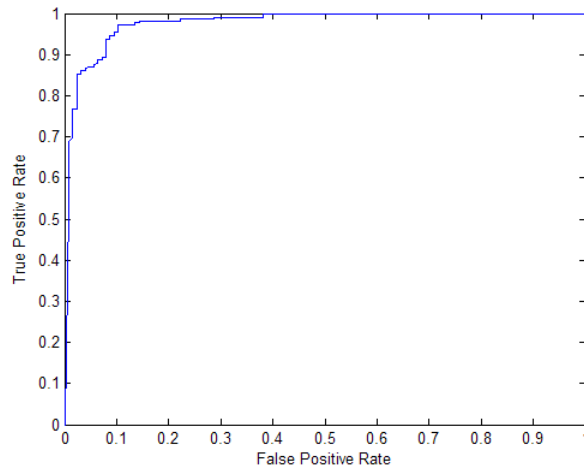
Plotting a Classification Performance Curve. Another way of exploring the performance of a classification ensemble is to plot its Receiver Operating Characteristic (ROC) curve or another performance curve suitable for the current problem. First, obtain predictions for out-of-bag observations. For a classification ensemble, the `oobPredict` method returns a cell array of classification labels ('g' or 'b' for ionosphere data) as the first output argument and a numeric array of scores as the second output argument. The returned array of scores has two columns, one for each class. In this case, the first column is for the 'good' class and the second column is for the 'bad' class. One column in the score matrix is redundant because the scores represent class probabilities in tree leaves and by definition add up to 1.

```
[Yfit,Sfit] = oobPredict(b5v);
```

Use the `perfcurve` utility (see “Performance Curves” on page 12-39) to compute a performance curve. By default, `perfcurve` returns the standard ROC curve, which is the true positive rate versus the false positive rate. `perfcurve` requires true class labels, scores, and the positive class label for input. In this case, choose the 'good' class as positive. The scores for this class are in the first column of `Sfit`.

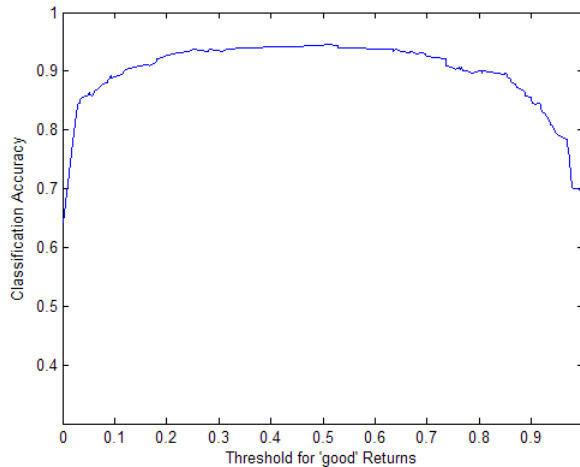
```
[fpr,tpr] = perfcurve(b5v.Y,Sfit(:,1),'g');
figure(19);
plot(fpr,tpr);
```

```
xlabel('False Positive Rate');
ylabel('True Positive Rate');
```



Instead of the standard ROC curve, you might want to plot, for example, ensemble accuracy versus threshold on the score for the 'good' class. The `ycrit` input argument of `perfcurve` lets you specify the criterion for the y -axis, and the third output argument of `perfcurve` returns an array of thresholds for the positive class score. Accuracy is the fraction of correctly classified observations, or equivalently, 1 minus the classification error.

```
[fpr,accu,thre] = perfcurve(b5v.Y,Sfit(:,1),'g','ycrit','accu');
figure(20);
plot(thre,accu);
xlabel('Threshold for ''good'' Returns');
ylabel('Classification Accuracy');
```



The curve shows a flat region indicating that any threshold from 0.2 to 0.6 is a reasonable choice. By default, the function assigns classification labels using 0.5 as the boundary between the two classes. You can find exactly what accuracy this corresponds to:

```
i50 = find(accu>=0.50,1,'first')
accu(abs(thre-0.5)<eps)
```

returns

```
i50 =
     2
```

```
ans =
     0.9430
```

The maximal accuracy is a little higher than the default one:

```
[maxaccu,iaccu] = max(accu)
```

returns

```
maxaccu =
     0.9459
```



```
iaccu =  
    91
```

The optimal threshold is therefore:

```
thre(iaccu)
```

```
ans =  
    0.5056
```

Ensemble Algorithms

- “AdaBoostM1” on page 13-141
- “AdaBoostM2” on page 13-143
- “Bag” on page 13-144
- “GentleBoost” on page 13-148
- “LogitBoost” on page 13-148
- “LPBoost” on page 13-150
- “LSBoost” on page 13-151
- “RobustBoost” on page 13-152
- “RUSBoost” on page 13-153
- “Subspace” on page 13-154
- “TotalBoost” on page 13-155

AdaBoostM1

AdaBoostM1 is a very popular boosting algorithm for binary classification. The algorithm trains learners sequentially. For every learner with index t , AdaBoostM1 computes the weighted classification error

$$\varepsilon_t = \sum_{n=1}^N d_n^{(t)} \mathbb{I}(y_n \neq h_t(x_n)),$$

where

- x_n is a vector of predictor values for observation n .
- y_n is the true class label.
- h_t is the prediction of learner (hypothesis) with index t .
- \mathbb{I} is the indicator function.
- $d_n^{(t)}$ is the weight of observation n at step t .

AdaBoostM1 then increases weights for observations misclassified by learner t and reduces weights for observations correctly classified by learner t . The next learner $t + 1$ is then trained on the data with updated weights $d_n^{(t+1)}$.

After training finishes, AdaBoostM1 computes prediction for new data using

$$f(x) = \sum_{t=1}^T \alpha_t h_t(x),$$

where

$$\alpha_t = \frac{1}{2} \log \frac{1 - \varepsilon_t}{\varepsilon_t}$$

are weights of the weak hypotheses in the ensemble.

Training by AdaBoostM1 can be viewed as stagewise minimization of the exponential loss

$$\sum_{n=1}^N w_n \exp(-y_n f(x_n)),$$

where

- $y_n \in \{-1, +1\}$ is the true class label.

- w_n are observation weights normalized to add up to 1.
- $f(x_n) \in (-\infty, +\infty)$ is the predicted classification score.

The observation weights w_n are the original observation weights you passed to `fitensemble`.

The second output from the `predict` method of an `AdaBoostM1` classification ensemble is an N -by-2 matrix of classification scores for the two classes and N observations. The second column in this matrix is always equal to minus the first column. `predict` returns two scores to be consistent with multiclass models, though this is redundant because the second column is always the negative of the first.

Most often `AdaBoostM1` is used with decision stumps (default) or shallow trees. If boosted stumps give poor performance, try setting the minimal parent node size to one quarter of the training data.

By default, the learning rate for boosting algorithms is 1. If you set the learning rate to a lower number, the ensemble learns at a slower rate, but can converge to a better solution. 0.1 is a popular choice for the learning rate. Learning at a rate less than 1 is often called “shrinkage”.

For examples using `AdaBoostM1`, see “Tuning `RobustBoost`” on page 13-110.

For references related to `AdaBoostM1`, see Freund and Schapire [7], Schapire et al. [12], Friedman, Hastie, and Tibshirani [9], and Friedman [8].

AdaBoostM2

`AdaBoostM2` is an extension of `AdaBoostM1` for multiple classes. Instead of weighted classification error, `AdaBoostM2` uses weighted pseudo-loss for N observations and K classes

$$\varepsilon_t = \frac{1}{2} \sum_{n=1}^N \sum_{k \neq y_n} d_{n,k}^{(t)} (1 - h_t(x_n, y_n) + h_t(x_n, k)),$$

where

- $h_t(x_n, k)$ is the confidence of prediction by learner at step t into class k ranging from 0 (not at all confident) to 1 (highly confident).
- $d_{n,k}^{(t)}$ are observation weights at step t for class k .
- y_n is the true class label taking one of the K values.
- The second sum is over all classes other than the true class y_n .

Interpreting the pseudo-loss is harder than classification error, but the idea is the same. Pseudo-loss can be used as a measure of the classification accuracy from any learner in an ensemble. Pseudo-loss typically exhibits the same behavior as a weighted classification error for AdaBoostM1: the first few learners in a boosted ensemble give low pseudo-loss values. After the first few training steps, the ensemble begins to learn at a slower pace, and the pseudo-loss value approaches 0.5 from below.

For examples using AdaBoostM2, see “Create a Classification Ensemble” on page 13-64.

For references related to AdaBoostM2, see Freund and Schapire [7].

Bag

Bagging, which stands for “bootstrap aggregation,” is a type of ensemble learning. To bag a weak learner such as a decision tree on a dataset, generate many bootstrap replicas of this dataset and grow decision trees on these replicas. Obtain each bootstrap replica by randomly selecting N observations out of N with replacement, where N is the dataset size. To find the predicted response of a trained ensemble, take an average over predictions from individual trees.

Bagged decision trees were introduced in MATLAB R2009a as `TreeBagger`. The `fitensemble` function lets you bag in a manner consistent with boosting. An ensemble of bagged trees, either `ClassificationBaggedEnsemble` or `RegressionBaggedEnsemble`, returned by `fitensemble` offers almost the same functionality as `TreeBagger`. Discrepancies between `TreeBagger` and the new framework are described in detail in `TreeBagger Features Not in fitensemble` on page 13-146.

Bagging works by training learners on resampled versions of the data. This resampling is usually done by bootstrapping observations, that is, selecting N out of N observations with replacement for every new learner. In addition, every tree in the ensemble can randomly select predictors for decision splits—a technique known to improve the accuracy of bagged trees.

By default, the minimal leaf sizes for bagged trees are set to 1 for classification and 5 for regression. Trees grown with the default leaf size are usually very deep. These settings are close to optimal for the predictive power of an ensemble. Often you can grow trees with larger leaves without losing predictive power. Doing so reduces training and prediction time, as well as memory usage for the trained ensemble.

Another important parameter is the number of predictors selected at random for every decision split. This random selection is made for every split, and every deep tree involves many splits. By default, this parameter is set to a square root of the number of predictors for classification, and one third of predictors for regression.

Several features of bagged decision trees make them a unique algorithm. Drawing N out of N observations with replacement omits on average 37% of observations for each decision tree. These are “out-of-bag” observations. You can use them to estimate the predictive power and feature importance. For each observation, you can estimate the out-of-bag prediction by averaging over predictions from all trees in the ensemble for which this observation is out of bag. You can then compare the computed prediction against the observed response for this observation. By comparing the out-of-bag predicted responses against the observed responses for all observations used for training, you can estimate the average out-of-bag error. This out-of-bag average is an unbiased estimator of the true ensemble error. You can also obtain out-of-bag estimates of feature importance by randomly permuting out-of-bag data across one variable or column at a time and estimating the increase in the out-of-bag error due to this permutation. The larger the increase, the more important the feature. Thus, you need not supply test data for bagged ensembles because you obtain reliable estimates of the predictive power and feature importance in the process of training, which is an attractive feature of bagging.

Another attractive feature of bagged decision trees is the proximity matrix. Every time two observations land on the same leaf of a tree, their proximity

increases by 1. For normalization, sum these proximities over all trees in the ensemble and divide by the number of trees. The resulting matrix is symmetric with diagonal elements equal to 1 and off-diagonal elements ranging from 0 to 1. You can use this matrix for finding outlier observations and discovering clusters in the data through multidimensional scaling.

For examples using bagging, see:

- “Example: Test Ensemble Quality” on page 13-66
- “Surrogate Splits” on page 13-88
- “Workflow Example: Regression of Insurance Risk Rating for Car Imports with TreeBagger” on page 13-120
- “Workflow Example: Classifying Radar Returns for Ionosphere Data with TreeBagger” on page 13-129

For references related to bagging, see Breiman [2], [3], and [4].

Comparison of TreeBagger and Bagged Ensembles. `fitensemble` produces bagged ensembles that have most, but not all, of the functionality of TreeBagger objects. Additionally, some functionality has different names in the new bagged ensembles.

TreeBagger Features Not in `fitensemble`

Feature	TreeBagger Property	TreeBagger Method
Computation of proximity matrix	Proximity	<code>fillProximities</code> , <code>mdsProx</code>
Computation of outliers	OutlierMeasure	N/A
Out-of-bag estimates of predictor importance	<code>OOBPermutedVarDeltaError</code> , <code>OOBPermutedVarDeltaMeanMargin</code> , <code>OOBPermutedVarCountRaiseMargin</code>	N/A
Merging two ensembles trained separately	N/A	<code>append</code>
Parallel computation for creating ensemble	Set the <code>UseParallel</code> name-value pair to 'always'	N/A

Differing Names Between TreeBagger and Bagged Ensembles

Feature	TreeBagger	Bagged Ensembles
Split criterion contributions for each predictor	DeltaCritDecisionSplit property	First output of predictorImportance (classification) or predictorImportance (regression)
Predictor associations	VarAssoc property	Second output of predictorImportance (classification) or predictorImportance (regression)
Error (misclassification probability or mean-squared error)	error and oobError methods	loss and oobLoss methods (classification); loss and oobLoss methods (regression)
Train additional trees and add to ensemble	growTrees method	resume method (classification); resume method (regression)
Mean classification margin per tree	meanMargin and oobMeanMargin methods	edge and oobEdge methods (classification)

In addition, two important changes were made to training and prediction for bagged classification ensembles:

- If you pass a misclassification cost matrix to `TreeBagger`, it passes this matrix along to the trees. If you pass a misclassification cost matrix to `fitensemble`, it uses this matrix to adjust the class prior probabilities. `fitensemble` then passes the adjusted prior probabilities and the default cost matrix to the trees. The default cost matrix is `ones(K) - eye(K)` for `K` classes.
- Unlike the `loss` and `edge` methods in the new framework, the `TreeBagger` `error` and `meanMargin` methods do not normalize input observation weights of the prior probabilities in the respective class.

GentleBoost

GentleBoost (also known as Gentle AdaBoost) combines features of AdaBoostM1 and LogitBoost. Like AdaBoostM1, GentleBoost minimizes the exponential loss. But its numeric optimization is set up differently. Like LogitBoost, every weak learner fits a regression model to response values $y_n \in \{-1, +1\}$. This makes GentleBoost another good candidate for binary classification of data with multilevel categorical predictors.

`fitensemble` computes and stores the mean-squared error in the `FitInfo` property of the ensemble object. The mean-squared error is

$$\sum_{n=1}^N d_n^{(t)} (\tilde{y}_n - h_t(x_n))^2,$$

where

- $d_n^{(t)}$ are observation weights at step t (the weights add up to 1).
- $h_t(x_n)$ are predictions of the regression model h_t fitted to response values y_n .

As the strength of individual learners weakens, the weighted mean-squared error approaches 1.

For examples using GentleBoost, see “Example: Unequal Classification Costs” on page 13-78 and “Classification with Many Categorical Levels” on page 13-83.

For references related to GentleBoost, see Friedman, Hastie, and Tibshirani [9].

LogitBoost

LogitBoost is another popular algorithm for binary classification. LogitBoost works similarly to AdaBoostM1, except it minimizes binomial deviance

$$\sum_{n=1}^N w_n \log(1 + \exp(-2y_n f(x_n))),$$

where

- $y_n \in \{-1, +1\}$ is the true class label.
- w_n are observation weights normalized to add up to 1.
- $f(x_n) \in (-\infty, +\infty)$ is the predicted classification score.

Binomial deviance assigns less weight to badly misclassified observations (observations with large negative values of $y_n f(x_n)$). `LogitBoost` can give better average accuracy than `AdaBoostM1` for data with poorly separable classes.

Learner t in a `LogitBoost` ensemble fits a regression model to response values

$$\tilde{y}_n = \frac{y_n^* - p_t(x_n)}{p_t(x_n)(1 - p_t(x_n))},$$

where

- $y_n^* \in \{0, +1\}$ are relabeled classes (0 instead of -1).
- $p_t(x_n)$ is the current ensemble estimate of the probability for observation x_n to be of class 1.

Fitting a regression model at each boosting step turns into a great computational advantage for data with multilevel categorical predictors. Take a categorical predictor with L levels. To find the optimal decision split on such a predictor, classification tree needs to consider $2^{L-1} - 1$ splits. A regression tree needs to consider only $L - 1$ splits, so the processing time can be much shorter. `LogitBoost` is recommended for categorical predictors with many levels.

`fitensemble` computes and stores the mean-squared error in the `FitInfo` property of the ensemble object. The mean-squared error is

$$\sum_{n=1}^N a_n^{(t)} (\tilde{y}_n - h_t(x_n))^2,$$

where

- $d_n^{(t)}$ are observation weights at step t (the weights add up to 1).
- $h_t(x_n)$ are predictions of the regression model h_t fitted to response values \tilde{y}_n .

Values y_n can range from $-\infty$ to $+\infty$, so the mean-squared error does not have well-defined bounds.

For examples using **LogitBoost**, see “Classification with Many Categorical Levels” on page 13-83.

For references related to **LogitBoost**, see Friedman, Hastie, and Tibshirani [9].

LPBoost

LPBoost (linear programming boost), like **TotalBoost**, performs multiclass classification by attempting to maximize the minimal *margin* in the training set. This attempt uses optimization algorithms, namely linear programming for **LPBoost**. So you need an Optimization Toolbox license to use **LPBoost** or **TotalBoost**.

The margin of a classification is the difference between the predicted soft classification *score* for the true class, and the largest score for the false classes. For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node. For more information, see “Definitions” on page 20-1270 in *margin*.

Why maximize the minimal margin? For one thing, the generalization error (the error on new data) is the probability of obtaining a negative margin. Schapire and Singer [13] establish this inequality on the probability of obtaining a negative margin:

$$P_{\text{test}}(m \leq 0) \leq P_{\text{train}}(m \leq \theta) + O\left(\frac{1}{\sqrt{N}} \sqrt{\frac{V \log^2(N/V)}{\theta^2} + \log(1/\delta)}\right).$$

Here m is the margin, θ is any positive number, V is the Vapnik-Chervonenkis dimension of the classifier space, N is the size of the training set, and δ is a small positive number. The inequality holds with probability $1-\delta$ over many i.i.d. training and test sets. This inequality says: To obtain a low generalization error, minimize the number of observations below margin θ in the training set.

LPBoost iteratively maximizes the minimal margin through a sequence of linear programming problems. Equivalently, by duality, LPBoost minimizes the maximal *edge*, where edge is the weighted mean margin (see “Definitions” on page 20-576). At each iteration, there are more constraints in the problem. So, for large problems, the optimization problem becomes increasingly constrained, and slow to solve.

LPBoost typically creates ensembles with many learners having weights that are orders of magnitude smaller than those of other learners. Therefore, to better enable you to remove the unimportant ensemble members, the compact method reorders the members of an LPBoost ensemble from largest weight to smallest. Therefore, you can easily remove the least important members of the ensemble using the `removeLearners` method.

For examples using LPBoost, see “LPBoost and TotalBoost for Small Ensembles” on page 13-93.

For references related to LPBoost, see Warmuth, Liao, and Ratsch [15].

LSBoost

LSBoost (least squares boosting) fits regression ensembles. At every step, the ensemble fits a new learner to the difference between the observed response and the aggregated prediction of all learners grown previously. The ensemble fits to minimize mean-squared error.

You can use LSBoost with shrinkage by passing in the `LearnRate` parameter. By default this parameter is set to 1, and the ensemble learns at the maximal speed. If you set `LearnRate` to a value from 0 to 1, the ensemble fits every new learner to $y_n - \eta f(x_n)$, where

- y_n is the observed response.

- $f(x_n)$ is the aggregated prediction from all weak learners grown so far for observation x_n .
- η is the learning rate.

For examples using `LSBoost`, see “Creating a Regression Ensemble” on page 13-65 and “Example: Regularizing a Regression Ensemble” on page 13-100.

For references related to `LSBoost`, see Hastie, Tibshirani, and Friedman [10], Chapters 7 (Model Assessment and Selection) and 15 (Random Forests).

RobustBoost

Boosting algorithms such as `AdaBoostM1` and `LogitBoost` increase weights for misclassified observations at every boosting step. These weights can become very large. If this happens, the boosting algorithm sometimes concentrates on a few misclassified observations and neglects the majority of training data. Consequently the average classification accuracy suffers.

In this situation, you can try using `RobustBoost`. This algorithm does not assign almost the entire data weight to badly misclassified observations. It can produce better average classification accuracy.

Unlike `AdaBoostM1` and `LogitBoost`, `RobustBoost` does not minimize a specific loss function. Instead, it maximizes the number of observations with the classification margin above a certain threshold.

`RobustBoost` trains based on time evolution. The algorithm starts at $t = 0$. At every step, `RobustBoost` solves an optimization problem to find a positive step in time Δt and a corresponding positive change in the average margin for training data Δm . `RobustBoost` stops training and exits if at least one of these three conditions is true:

- Time t reaches 1.
- `RobustBoost` cannot find a solution to the optimization problem with positive updates Δt and Δm .
- `RobustBoost` grows as many learners as you requested.

Results from `RobustBoost` can be usable for any termination condition. Estimate the classification accuracy by cross validation or by using an independent test set.

To get better classification accuracy from `RobustBoost`, you can adjust three parameters in `fitensemble`: `RobustErrorGoal`, `RobustMaxMargin`, and `RobustMarginSigma`. Start by varying values for `RobustErrorGoal` from 0 to 1. The maximal allowed value for `RobustErrorGoal` depends on the two other parameters. If you pass a value that is too high, `fitensemble` produces an error message showing the allowed range for `RobustErrorGoal`.

For examples using `RobustBoost`, see “Tuning `RobustBoost`” on page 13-110.

For references related to `RobustBoost`, see Freund [6].

RUSBoost

`RUSBoost` is especially effective at classifying imbalanced data, meaning some class in the training data has many fewer members than another. `RUS` stands for Random Under Sampling. The algorithm takes N , the number of members in the class with the fewest members in the training data, as the basic unit for sampling. Classes with more members are under sampled by taking only N observations of every class. In other words, if there are K classes, then, for each weak learner in the ensemble, `RUSBoost` takes a subset of the data with N observations from each of the K classes. The boosting procedure follows the procedure in “`AdaBoostM2`” on page 13-143 for reweighting and constructing the ensemble.

When you construct a `RUSBoost` ensemble, there is an optional name-value pair called `RatioToSmallest`. Give a vector of K values, each value representing the multiple of N to sample for the associated class. For example, if the smallest class has $N = 100$ members, then `RatioToSmallest = [2,3,4]` means each weak learner has 200 members in class 1, 300 in class 2, and 400 in class 3. If `RatioToSmallest` leads to a value that is larger than the number of members in a particular class, then `RUSBoost` samples the members with replacement. Otherwise, `RUSBoost` samples the members without replacement.

For examples using `RUSBoost`, see “Classification with Imbalanced Data” on page 13-71.

For references related to RUSBoost, see Seiffert et al. [14].

Subspace

Use random subspace ensembles (`Subspace`) to improve the accuracy of discriminant analysis (`ClassificationDiscriminant`) or k -nearest neighbor (`ClassificationKNN`) classifiers. `Subspace` ensembles also have the advantage of using less memory than ensembles with all predictors, and can handle missing values (NaNs).

The basic random subspace algorithm uses these parameters.

- m is the number of dimensions (variables) to sample in each learner. Set m using the `NPredToSample` name-value pair.
- d is the number of dimensions in the data, which is the number of columns (predictors) in the data matrix X .
- n is the number of learners in the ensemble. Set n using the `NLearn` input.

The basic random subspace algorithm performs the following steps:

- 1** Choose without replacement a random set of m predictors from the d possible values.
- 2** Train a weak learner using just the m chosen predictors.
- 3** Repeat steps 1 and 2 until there are n weak learners.
- 4** Predict by taking an average of the score prediction of the weak learners, and classify the category with the highest average score.

You can choose to create a weak learner for every possible set of m predictors from the d dimensions. To do so, set n , the number of learners, to `'AllPredictorCombinations'`. In this case, there are `nchoosek(size(X,2),NPredToSample)` weak learners in the ensemble.

`fitensemble` downweights predictors after choosing them for a learner, so subsequent learners have a lower chance of using a predictor that was previously used. This weighting tends to make predictors more evenly distributed among learners than in uniform weighting.

For examples using `Subspace`, see “Random Subspace Classification” on page 13-114.

For references related to random subspace ensembles, see Ho [11].

TotalBoost

`TotalBoost`, like linear programming boost (`LPBoost`), performs multiclass classification by attempting to maximize the minimal *margin* in the training set. This attempt uses optimization algorithms, namely quadratic programming for `TotalBoost`. So you need an Optimization Toolbox license to use `LPBoost` or `TotalBoost`.

The margin of a classification is the difference between the predicted soft classification *score* for the true class, and the largest score for the false classes. For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node. For more information, see “Definitions” on page 20-1270 in `margin`.

Why maximize the minimal margin? For one thing, the generalization error (the error on new data) is the probability of obtaining a negative margin. Schapire and Singer [13] establish this inequality on the probability of obtaining a negative margin:

$$P_{\text{test}}(m \leq 0) \leq P_{\text{train}}(m \leq \theta) + O\left(\frac{1}{\sqrt{N}} \sqrt{\frac{V \log^2(N/V)}{\theta^2} + \log(1/\delta)}\right).$$

Here m is the margin, θ is any positive number, V is the Vapnik-Chervonenkis dimension of the classifier space, N is the size of the training set, and δ is a small positive number. The inequality holds with probability $1-\delta$ over many i.i.d. training and test sets. This inequality says: To obtain a low generalization error, minimize the number of observations below margin θ in the training set.

`TotalBoost` minimizes a proxy of the Kullback-Leibler divergence between the current weight distribution and the initial weight distribution, subject to

the constraint that the *edge* (the weighted margin) is below a certain value. The proxy is a quadratic expansion of the divergence:

$$D(W, W_0) = \sum_{n=1}^N \log \frac{W(n)}{W_0(n)} \approx \sum_{n=1}^N \left(1 + \frac{W(n)}{W_0(n)} \right) \Delta + \frac{1}{2W(n)} \Delta^2,$$

where Δ is the difference between $W(n)$, the weights at the current and next iteration, and W_0 , the initial weight distribution, which is uniform. This optimization formulation keeps weights from becoming zero. At each iteration, there are more constraints in the problem. So, for large problems, the optimization problem becomes increasingly constrained, and slow to solve.

TotalBoost typically creates ensembles with many learners having weights that are orders of magnitude smaller than those of other learners. Therefore, to better enable you to remove the unimportant ensemble members, the compact method reorders the members of a TotalBoost ensemble from largest weight to smallest. Therefore you can easily remove the least important members of the ensemble using the `removeLearners` method.

For examples using TotalBoost, see “LPBoost and TotalBoost for Small Ensembles” on page 13-93.

For references related to TotalBoost, see Warmuth, Liao, and Ratsch [15].

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Markov Models

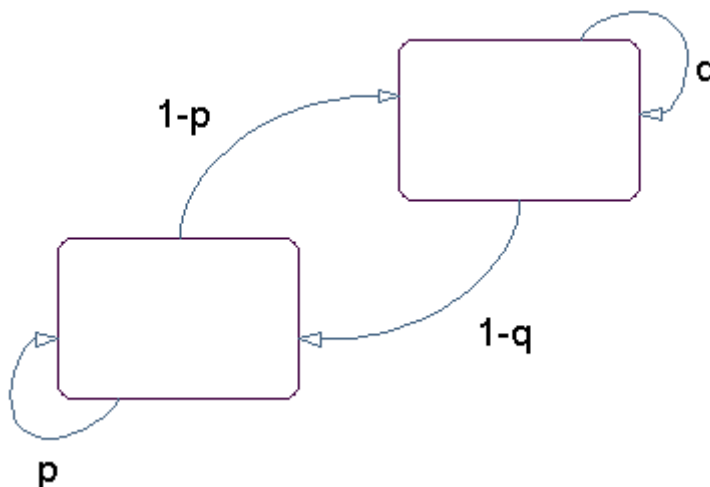
- “Introduction to Markov Models” on page 14-2
- “Markov Chains” on page 14-3
- “Hidden Markov Models (HMM)” on page 14-5

Introduction to Markov Models

Markov processes are examples of stochastic processes—processes that generate random sequences of outcomes or *states* according to certain probabilities. Markov processes are distinguished by being memoryless—their next state depends only on their current state, not on the history that led them there. Models of Markov processes are used in a wide variety of applications, from daily stock prices to the positions of genes in a chromosome.

Markov Chains

A Markov model is given visual representation with a *state diagram*, such as the one below.



State Diagram for a Markov Model

The rectangles in the diagram represent the possible states of the process you are trying to model, and the arrows represent transitions between states. The label on each arrow represents the probability of that transition. At each step of the process, the model may generate an output, or *emission*, depending on which state it is in, and then make a transition to another state. An important characteristic of Markov models is that the next state depends only on the current state, and not on the history of transitions that lead to the current state.

For example, for a sequence of coin tosses the two states are heads and tails. The most recent coin toss determines the current state of the model and each subsequent toss determines the transition to the next state. If the coin is fair, the transition probabilities are all $1/2$. The emission might simply be the current state. In more complicated models, random processes at each state will generate emissions. You could, for example, roll a die to determine the emission at any step.

Markov chains are mathematical descriptions of Markov models with a discrete set of states. Markov chains are characterized by:

- A set of states $\{1, 2, \dots, M\}$
- An M -by- M *transition matrix* T whose i,j entry is the probability of a transition from state i to state j . The sum of the entries in each row of T must be 1, because this is the sum of the probabilities of making a transition from a given state to each of the other states.
- A set of possible outputs, or *emissions*, $\{s_1, s_2, \dots, s_N\}$. By default, the set of emissions is $\{1, 2, \dots, N\}$, where N is the number of possible emissions, but you can choose a different set of numbers or symbols.
- An M -by- N *emission matrix* E whose i,k entry gives the probability of emitting symbol s_k given that the model is in state i .

Markov chains begin in an *initial state* i_0 at step 0. The chain then transitions to state i_1 with probability T_{1i_1} , and emits an output s_{k_1} with probability $E_{i_1k_1}$. Consequently, the probability of observing the sequence of states $i_1i_2\dots i_r$ and the sequence of emissions $s_{k_1}s_{k_2}\dots s_{k_r}$ in the first r steps, is

$$T_{1i_1} E_{i_1k_1} T_{i_1i_2} E_{i_2k_2} \dots T_{i_{r-1}i_r} E_{i_rk_r}$$

Hidden Markov Models (HMM)

In this section...
“Introduction to Hidden Markov Models (HMM)” on page 14-5
“Analyzing Hidden Markov Models” on page 14-7

Introduction to Hidden Markov Models (HMM)

A *hidden Markov model* (HMM) is one in which you observe a sequence of emissions, but do not know the sequence of states the model went through to generate the emissions. Analyses of hidden Markov models seek to recover the sequence of states from the observed data.

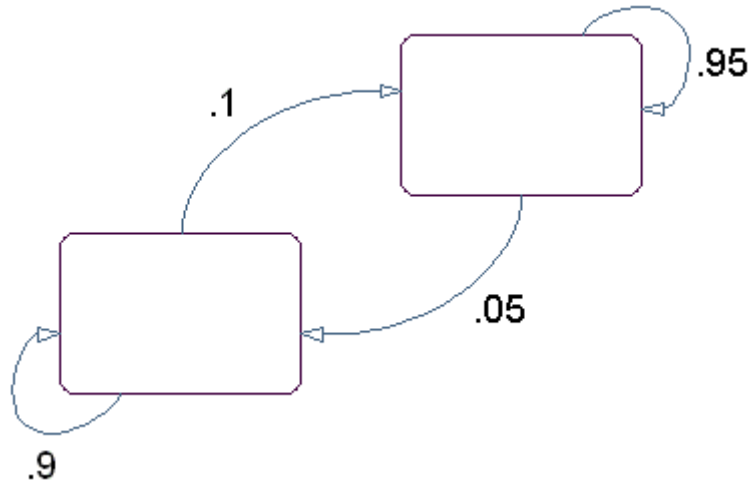
As an example, consider a Markov model with two states and six possible emissions. The model uses:

- A red die, having six sides, labeled 1 through 6.
- A green die, having twelve sides, five of which are labeled 2 through 6, while the remaining seven sides are labeled 1.
- A weighted red coin, for which the probability of heads is .9 and the probability of tails is .1.
- A weighted green coin, for which the probability of heads is .95 and the probability of tails is .05.

The model creates a sequence of numbers from the set {1, 2, 3, 4, 5, 6} with the following rules:

- Begin by rolling the red die and writing down the number that comes up, which is the emission.
- Toss the red coin and do one of the following:
 - If the result is heads, roll the red die and write down the result.
 - If the result is tails, roll the green die and write down the result.
- At each subsequent step, you flip the coin that has the same color as the die you rolled in the previous step. If the coin comes up heads, roll the same die as in the previous step. If the coin comes up tails, switch to the other die.

The state diagram for this model has two states, red and green, as shown in the following figure.



You determine the emission from a state by rolling the die with the same color as the state. You determine the transition to the next state by flipping the coin with the same color as the state.

The transition matrix is:

$$T = \begin{bmatrix} 0.9 & 0.1 \\ 0.05 & 0.95 \end{bmatrix}$$

The emissions matrix is:

$$E = \begin{bmatrix} \frac{1}{6} & \frac{1}{6} & \frac{1}{6} & \frac{1}{6} & \frac{1}{6} & \frac{1}{6} \\ \frac{7}{12} & \frac{1}{12} & \frac{1}{12} & \frac{1}{12} & \frac{1}{12} & \frac{1}{12} \end{bmatrix}$$

The model is not hidden because you know the sequence of states from the colors of the coins and dice. Suppose, however, that someone else is generating

the emissions without showing you the dice or the coins. All you see is the sequence of emissions. If you start seeing more 1s than other numbers, you might suspect that the model is in the green state, but you cannot be sure because you cannot see the color of the die being rolled.

Hidden Markov models raise the following questions:

- Given a sequence of emissions, what is the most likely state path?
- Given a sequence of emissions, how can you estimate transition and emission probabilities of the model?
- What is the *forward probability* that the model generates a given sequence?
- What is the *posterior probability* that the model is in a particular state at any point in the sequence?

Analyzing Hidden Markov Models

- “Generating a Test Sequence” on page 14-8
- “Estimating the State Sequence” on page 14-8
- “Estimating Transition and Emission Matrices” on page 14-9
- “Estimating Posterior State Probabilities” on page 14-11
- “Changing the Initial State Distribution” on page 14-12

Statistics Toolbox functions related to hidden Markov models are:

- `hmmgenerate` — Generates a sequence of states and emissions from a Markov model
- `hmmestimate` — Calculates maximum likelihood estimates of transition and emission probabilities from a sequence of emissions and a known sequence of states
- `hmmtrain` — Calculates maximum likelihood estimates of transition and emission probabilities from a sequence of emissions
- `hmmviterbi` — Calculates the most probable state path for a hidden Markov model

- `hmmdecode` — Calculates the posterior state probabilities of a sequence of emissions

This section shows how to use these functions to analyze hidden Markov models.

Generating a Test Sequence

The following commands create the transition and emission matrices for the model described in the “Introduction to Hidden Markov Models (HMM)” on page 14-5:

```
TRANS = [.9 .1; .05 .95];  
  
EMIS = [1/6, 1/6, 1/6, 1/6, 1/6, 1/6;...  
7/12, 1/12, 1/12, 1/12, 1/12, 1/12];
```

To generate a random sequence of states and emissions from the model, use `hmmgenerate`:

```
[seq,states] = hmmgenerate(1000,TRANS,EMIS);
```

The output `seq` is the sequence of emissions and the output `states` is the sequence of states.

`hmmgenerate` begins in state 1 at step 0, makes the transition to state i_1 at step 1, and returns i_1 as the first entry in `states`. To change the initial state, see “Changing the Initial State Distribution” on page 14-12.

Estimating the State Sequence

Given the transition and emission matrices `TRANS` and `EMIS`, the function `hmmviterbi` uses the Viterbi algorithm to compute the most likely sequence of states the model would go through to generate a given sequence `seq` of emissions:

```
likelystates = hmmviterbi(seq, TRANS, EMIS);
```

`likelystates` is a sequence the same length as `seq`.

To test the accuracy of `hmmviterbi`, compute the percentage of the actual sequence `states` that agrees with the sequence `likelystates`.

```
sum(states==likelystates)/1000
ans =
    0.8200
```

In this case, the most likely sequence of states agrees with the random sequence 82% of the time.

Estimating Transition and Emission Matrices

- “Using `hmmestimate`” on page 14-9
- “Using `hmmtrain`” on page 14-10

The functions `hmmestimate` and `hmmtrain` estimate the transition and emission matrices `TRANS` and `EMIS` given a sequence `seq` of emissions.

Using `hmmestimate`. The function `hmmestimate` requires that you know the sequence of states `states` that the model went through to generate `seq`.

The following takes the emission and state sequences and returns estimates of the transition and emission matrices:

```
[TRANS_EST, EMIS_EST] = hmmestimate(seq, states)

TRANS_EST =
    0.8989    0.1011
    0.0585    0.9415

EMIS_EST =
    0.1721    0.1721    0.1749    0.1612    0.1803    0.1393
    0.5836    0.0741    0.0804    0.0789    0.0726    0.1104
```

You can compare the outputs with the original transition and emission matrices, `TRANS` and `EMIS`:

```
TRANS
TRANS =
    0.9000    0.1000
    0.0500    0.9500

EMIS
```

```
EMIS =  
0.1667    0.1667    0.1667    0.1667    0.1667    0.1667  
0.5833    0.0833    0.0833    0.0833    0.0833    0.0833
```

Using `hmmtrain`. If you do not know the sequence of states `states`, but you have initial guesses for `TRANS` and `EMIS`, you can still estimate `TRANS` and `EMIS` using `hmmtrain`.

Suppose you have the following initial guesses for `TRANS` and `EMIS`.

```
TRANS_GUESS = [.85 .15; .1 .9];  
EMIS_GUESS = [.17 .16 .17 .16 .17 .17;.6 .08 .08 .08 .08 08];
```

You estimate `TRANS` and `EMIS` as follows:

```
[TRANS_EST2, EMIS_EST2] = hmmtrain(seq, TRANS_GUESS, EMIS_GUESS)
```

```
TRANS_EST2 =  
0.2286    0.7714  
0.0032    0.9968
```

```
EMIS_EST2 =  
0.1436    0.2348    0.1837    0.1963    0.2350    0.0066  
0.4355    0.1089    0.1144    0.1082    0.1109    0.1220
```

`hmmtrain` uses an iterative algorithm that alters the matrices `TRANS_GUESS` and `EMIS_GUESS` so that at each step the adjusted matrices are more likely to generate the observed sequence, `seq`. The algorithm halts when the matrices in two successive iterations are within a small tolerance of each other.

If the algorithm fails to reach this tolerance within a maximum number of iterations, whose default value is 100, the algorithm halts. In this case, `hmmtrain` returns the last values of `TRANS_EST` and `EMIS_EST` and issues a warning that the tolerance was not reached.

If the algorithm fails to reach the desired tolerance, increase the default value of the maximum number of iterations with the command:

```
hmmtrain(seq, TRANS_GUESS, EMIS_GUESS, 'maxiterations', maxiter)
```

where `maxiter` is the maximum number of steps the algorithm executes.

Change the default value of the tolerance with the command:

```
hmmtrain(seq, TRANS_GUESS, EMIS_GUESS, 'tolerance', tol)
```

where `tol` is the desired value of the tolerance. Increasing the value of `tol` makes the algorithm halt sooner, but the results are less accurate.

Two factors reduce the reliability of the output matrices of `hmmtrain`:

- The algorithm converges to a local maximum that does not represent the true transition and emission matrices. If you suspect this, use different initial guesses for the matrices `TRANS_EST` and `EMIS_EST`.
- The sequence `seq` may be too short to properly train the matrices. If you suspect this, use a longer sequence for `seq`.

Estimating Posterior State Probabilities

The posterior state probabilities of an emission sequence `seq` are the conditional probabilities that the model is in a particular state when it generates a symbol in `seq`, given that `seq` is emitted. You compute the posterior state probabilities with `hmmdecode`:

```
PSTATES = hmmdecode(seq, TRANS, EMIS)
```

The output `PSTATES` is an M -by- L matrix, where M is the number of states and L is the length of `seq`. `PSTATES(i, j)` is the conditional probability that the model is in state i when it generates the j th symbol of `seq`, given that `seq` is emitted.

`hmmdecode` begins with the model in state 1 at step 0, prior to the first emission. `PSTATES(i, 1)` is the probability that the model is in state i at the following step 1. To change the initial state, see “Changing the Initial State Distribution” on page 14-12.

To return the logarithm of the probability of the sequence `seq`, use the second output argument of `hmmdecode`:

```
[PSTATES, logpseq] = hmmdecode(seq, TRANS, EMIS)
```

The probability of a sequence tends to 0 as the length of the sequence increases, and the probability of a sufficiently long sequence becomes less

than the smallest positive number your computer can represent. `hmmdecode` returns the logarithm of the probability to avoid this problem.

Changing the Initial State Distribution

By default, Statistics Toolbox hidden Markov model functions begin in state 1. In other words, the distribution of initial states has all of its probability mass concentrated at state 1. To assign a different distribution of probabilities, $p = [p_1, p_2, \dots, p_M]$, to the M initial states, do the following:

- 1 Create an $M+1$ -by- $M+1$ augmented transition matrix, \hat{T} of the following form:

$$\hat{T} = \begin{bmatrix} 0 & p \\ 0 & T \end{bmatrix}$$

where T is the true transition matrix. The first column of \hat{T} contains $M+1$ zeros. p must sum to 1.

- 2 Create an $M+1$ -by- N augmented emission matrix, \hat{E} , that has the following form:

$$\hat{E} = \begin{bmatrix} 0 \\ E \end{bmatrix}$$

If the transition and emission matrices are `TRANS` and `EMIS`, respectively, you create the augmented matrices with the following commands:

```
TRANS_HAT = [0 p; zeros(size(TRANS,1),1) TRANS];
```

```
EMIS_HAT = [zeros(1,size(EMIS,2)); EMIS];
```

Design of Experiments

- “Design of Experiments” on page 15-2
- “Full Factorial Designs” on page 15-3
- “Fractional Factorial Designs” on page 15-5
- “Response Surface Designs” on page 15-9
- “D-Optimal Designs” on page 15-15

Design of Experiments

Passive data collection leads to a number of problems in statistical modeling. Observed changes in a response variable may be correlated with, but not caused by, observed changes in individual *factors* (process variables). Simultaneous changes in multiple factors may produce interactions that are difficult to separate into individual effects. Observations may be dependent, while a model of the data considers them to be independent.

Designed experiments address these problems. In a designed experiment, the data-producing process is actively manipulated to improve the quality of information and to eliminate redundant data. A common goal of all experimental designs is to collect data as parsimoniously as possible while providing sufficient information to accurately estimate model parameters.

For example, a simple model of a response y in an experiment with two controlled factors x_1 and x_2 might look like this:

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_1x_2 + \varepsilon$$

Here ε includes both experimental error and the effects of any uncontrolled factors in the experiment. The terms β_1x_1 and β_2x_2 are *main effects* and the term $\beta_3x_1x_2$ is a two-way *interaction effect*. A designed experiment would systematically manipulate x_1 and x_2 while measuring y , with the objective of accurately estimating β_0 , β_1 , β_2 , and β_3 .

Full Factorial Designs

In this section...

“Multilevel Designs” on page 15-3

“Two-Level Designs” on page 15-4

Multilevel Designs

To systematically vary experimental factors, assign each factor a discrete set of *levels*. Full factorial designs measure response variables using every *treatment* (combination of the factor levels). A full factorial design for n factors with N_1, \dots, N_n levels requires $N_1 \times \dots \times N_n$ experimental runs—one for each treatment. While advantageous for separating individual effects, full factorial designs can make large demands on data collection.

As an example, suppose a machine shop has three machines and four operators. If the same operator always uses the same machine, it is impossible to determine if a machine or an operator is the cause of variation in production. By allowing every operator to use every machine, effects are separated. A full factorial list of treatments is generated by the Statistics Toolbox function `fullfact`:

```
dFF = fullfact([3,4])
```

```
dFF =
```

```

1     1
2     1
3     1
1     2
2     2
3     2
1     3
2     3
3     3
1     4
2     4
3     4
```

Each of the $3 \times 4 = 12$ rows of `dFF` represent one machine/operator combination.

Two-Level Designs

Many experiments can be conducted with two-level factors, using *two-level designs*. For example, suppose the machine shop in the previous example always keeps the same operator on the same machine, but wants to measure production effects that depend on the composition of the day and night shifts. The Statistics Toolbox function `ff2n` generates a full factorial list of treatments:

```
dFF2 = ff2n(4)
dFF2 =
    0     0     0     0
    0     0     0     1
    0     0     1     0
    0     0     1     1
    0     1     0     0
    0     1     0     1
    0     1     1     0
    0     1     1     1
    1     0     0     0
    1     0     0     1
    1     0     1     0
    1     0     1     1
    1     1     0     0
    1     1     0     1
    1     1     1     0
    1     1     1     1
```

Each of the $2^4 = 16$ rows of `dFF2` represent one schedule of operators for the day (0) and night (1) shifts.

Fractional Factorial Designs

In this section...

“Introduction to Fractional Factorial Designs” on page 15-5

“Plackett-Burman Designs” on page 15-5

“General Fractional Designs” on page 15-6

Introduction to Fractional Factorial Designs

Two-level designs are sufficient for evaluating many production processes. Factor levels of ± 1 can indicate categorical factors, normalized factor extremes, or simply “up” and “down” from current factor settings. Experimenters evaluating process *changes* are interested primarily in the factor directions that lead to process improvement.

For experiments with many factors, two-level full factorial designs can lead to large amounts of data. For example, a two-level full factorial design with 10 factors requires $2^{10} = 1024$ runs. Often, however, individual factors or their interactions have no distinguishable effects on a response. This is especially true of higher order interactions. As a result, a well-designed experiment can use fewer runs for estimating model parameters.

Fractional factorial designs use a fraction of the runs required by full factorial designs. A subset of experimental treatments is selected based on an evaluation (or assumption) of which factors and interactions have the most significant effects. Once this selection is made, the experimental design must separate these effects. In particular, significant effects should not be *confounded*, that is, the measurement of one should not depend on the measurement of another.

Plackett-Burman Designs

Plackett-Burman designs are used when only main effects are considered significant. Two-level Plackett-Burman designs require a number of experimental runs that are a multiple of 4 rather than a power of 2. The MATLAB function `hadamard` generates these designs:

```
dPB = hadamard(8)
```

```
dPB =
  1  1  1  1  1  1  1  1
  1 -1  1 -1  1 -1  1 -1
  1  1 -1 -1  1  1 -1 -1
  1 -1 -1  1  1 -1 -1  1
  1  1  1  1 -1 -1 -1 -1
  1 -1  1 -1 -1  1 -1  1
  1  1 -1 -1 -1 -1  1  1
  1 -1 -1  1 -1  1  1 -1
```

Binary factor levels are indicated by ± 1 . The design is for eight runs (the rows of dPB) manipulating seven two-level factors (the last seven columns of dPB). The number of runs is a fraction $8/2^7 = 0.0625$ of the runs required by a full factorial design. Economy is achieved at the expense of confounding main effects with any two-way interactions.

General Fractional Designs

At the cost of a larger fractional design, you can specify which interactions you wish to consider significant. A design of *resolution R* is one in which no n -factor interaction is confounded with any other effect containing less than $R - n$ factors. Thus, a resolution III design does not confound main effects with one another but may confound them with two-way interactions (as in “Plackett-Burman Designs” on page 15-5), while a resolution IV design does not confound either main effects or two-way interactions but may confound two-way interactions with each other.

Specify general fractional factorial designs using a full factorial design for a selected subset of *basic factors* and *generators* for the remaining factors. Generators are products of the basic factors, giving the levels for the remaining factors. Use the Statistics Toolbox function `fracfact` to generate these designs:

```
dfF = fracfact('a b c d bcd acd')
dfF =
  -1  -1  -1  -1  -1  -1
  -1  -1  -1  1  1  1
  -1  -1  1  -1  1  1
  -1  -1  1  1  -1  -1
  -1  1  -1  -1  1  -1
```

-1	1	-1	1	-1	1
-1	1	1	-1	-1	1
-1	1	1	1	1	-1
1	-1	-1	-1	-1	1
1	-1	-1	1	1	-1
1	-1	1	-1	1	-1
1	-1	1	1	-1	1
1	1	-1	-1	1	1
1	1	-1	1	-1	-1
1	1	1	-1	-1	-1
1	1	1	1	1	1

This is a six-factor design in which four two-level basic factors (a, b, c, and d in the first four columns of `dfF`) are measured in every combination of levels, while the two remaining factors (in the last three columns of `dfF`) are measured only at levels defined by the generators `bcd` and `acd`, respectively. Levels in the generated columns are products of corresponding levels in the columns that make up the generator.

The challenge of creating a fractional factorial design is to choose basic factors and generators so that the design achieves a specified resolution in a specified number of runs. Use the Statistics Toolbox function `fracfactgen` to find appropriate generators:

```
generators = fracfactgen('a b c d e f',4,4)
generators =
    'a'
    'b'
    'c'
    'd'
    'bcd'
    'acd'
```

These are generators for a six-factor design with factors a through f, using $2^4 = 16$ runs to achieve resolution IV. The `fracfactgen` function uses an efficient search algorithm to find generators that meet the requirements.

An optional output from `fracfact` displays the *confounding pattern* of the design:

```
[dfF,confounding] = fracfact(generators);
```

```

confounding
confounding =
  'Term'      'Generator'  'Confounding'
  'X1'        'a'          'X1'
  'X2'        'b'          'X2'
  'X3'        'c'          'X3'
  'X4'        'd'          'X4'
  'X5'        'bcd'       'X5'
  'X6'        'acd'       'X6'
  'X1*X2'     'ab'        'X1*X2 + X5*X6'
  'X1*X3'     'ac'        'X1*X3 + X4*X6'
  'X1*X4'     'ad'        'X1*X4 + X3*X6'
  'X1*X5'     'abcd'      'X1*X5 + X2*X6'
  'X1*X6'     'cd'        'X1*X6 + X2*X5 + X3*X4'
  'X2*X3'     'bc'        'X2*X3 + X4*X5'
  'X2*X4'     'bd'        'X2*X4 + X3*X5'
  'X2*X5'     'cd'        'X1*X6 + X2*X5 + X3*X4'
  'X2*X6'     'abcd'      'X1*X5 + X2*X6'
  'X3*X4'     'cd'        'X1*X6 + X2*X5 + X3*X4'
  'X3*X5'     'bd'        'X2*X4 + X3*X5'
  'X3*X6'     'ad'        'X1*X4 + X3*X6'
  'X4*X5'     'bc'        'X2*X3 + X4*X5'
  'X4*X6'     'ac'        'X1*X3 + X4*X6'
  'X5*X6'     'ab'        'X1*X2 + X5*X6'

```

The confounding pattern shows that main effects are effectively separated by the design, but two-way interactions are confounded with various other two-way interactions.

Response Surface Designs

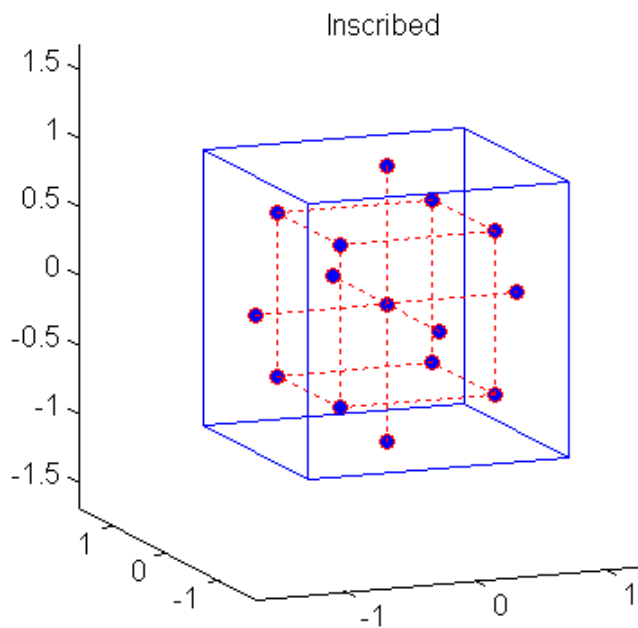
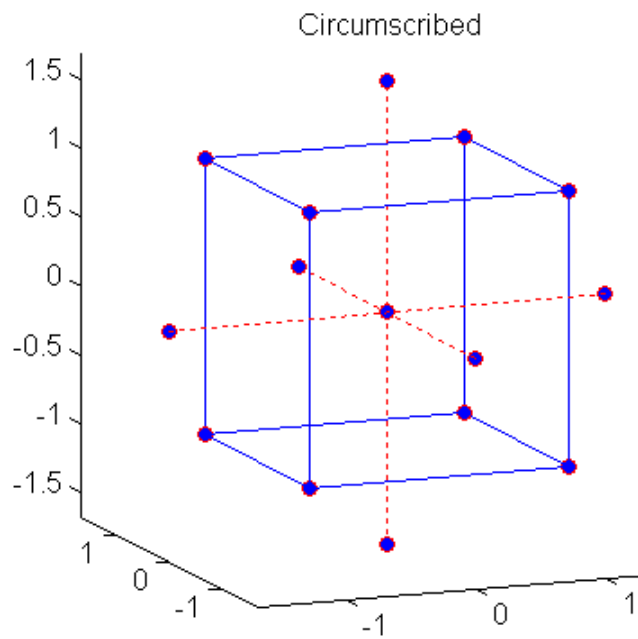
In this section...
“Introduction to Response Surface Designs” on page 15-9
“Central Composite Designs” on page 15-9
“Box-Behnken Designs” on page 15-13

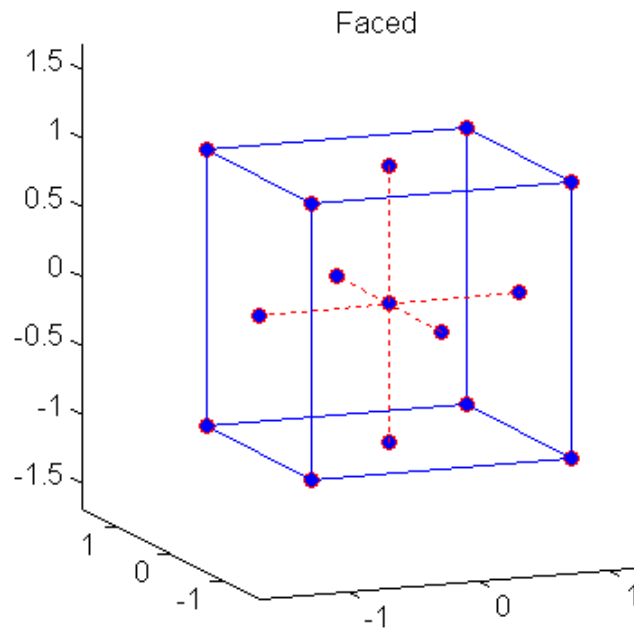
Introduction to Response Surface Designs

Quadratic response surfaces are simple models that provide a maximum or minimum without making additional assumptions about the form of the response. Quadratic models can be calibrated using full factorial designs with three or more levels for each factor, but these designs generally require more runs than necessary to accurately estimate model parameters. This section discusses designs for calibrating quadratic models that are much more efficient, using three or five levels for each factor, but not using all combinations of levels.

Central Composite Designs

Central composite designs (CCDs), also known as Box-Wilson designs, are appropriate for calibrating full quadratic models. There are three types of CCDs—circumscribed, inscribed, and faced—pictured below:





Each design consists of a factorial design (the corners of a cube) together with *center* and *star* points that allow for estimation of second-order effects. For a full quadratic model with n factors, CCDs have enough design points to estimate the $(n+2)(n+1)/2$ coefficients in a full quadratic model with n factors.

The type of CCD used (the position of the factorial and star points) is determined by the number of factors and by the desired properties of the design. The following table summarizes some important properties. A design is *rotatable* if the prediction variance depends only on the distance of the design point from the center of the design.

Design	Rotatable	Factor Levels	Uses Points Outside ± 1	Accuracy of Estimates
Circumscribed (CCC)	Yes	5	Yes	Good over entire design space
Inscribed (CCI)	Yes	5	No	Good over central subset of design space
Faced (CCF)	No	3	No	Fair over entire design space; poor for pure quadratic coefficients

Generate CCDs with the Statistics Toolbox function `ccdesign`:

```
dCC = ccdesign(3,'type','circumscribed')
```

```
dCC =
```

```
-1.0000 -1.0000 -1.0000
-1.0000 -1.0000  1.0000
-1.0000  1.0000 -1.0000
-1.0000  1.0000  1.0000
 1.0000 -1.0000 -1.0000
 1.0000 -1.0000  1.0000
 1.0000  1.0000 -1.0000
 1.0000  1.0000  1.0000
-1.6818         0         0
 1.6818         0         0
         0 -1.6818         0
         0  1.6818         0
         0         0 -1.6818
         0         0  1.6818
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
         0         0         0
```

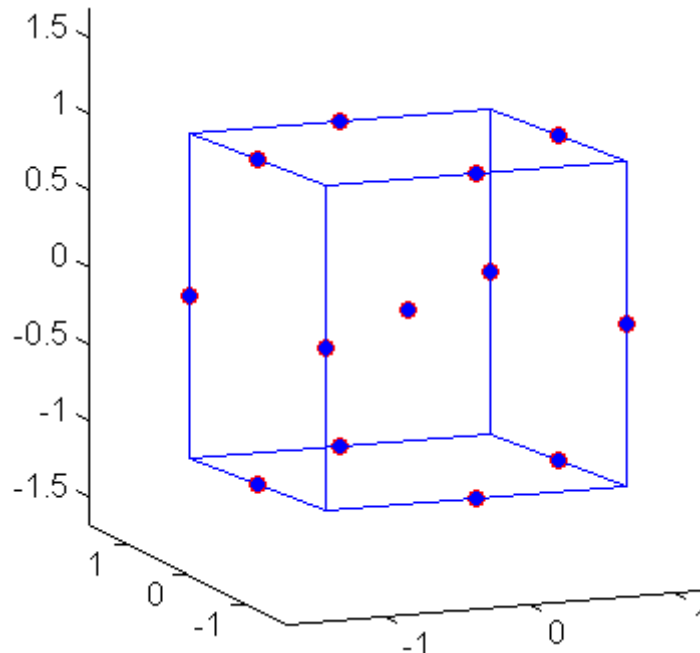
0 0 0

The repeated center point runs allow for a more uniform estimate of the prediction variance over the entire design space.

Box-Behnken Designs

Like the designs described in “Central Composite Designs” on page 15-9, Box-Behnken designs are used to calibrate full quadratic models. Box-Behnken designs are rotatable and, for a small number of factors (four or less), require fewer runs than CCDs. By avoiding the corners of the design space, they allow experimenters to work around extreme factor combinations. Like an inscribed CCD, however, extremes are then poorly estimated.

The geometry of a Box-Behnken design is pictured in the following figure.



Design points are at the midpoints of edges of the design space and at the center, and do not contain an embedded factorial design.

Generate Box-Behnken designs with the Statistics Toolbox function `bbdesign`:

```
dBB = bbdesign(3)
dBB =
    -1    -1     0
    -1     1     0
     1    -1     0
     1     1     0
    -1     0    -1
    -1     0     1
     1     0    -1
     1     0     1
     0    -1    -1
     0    -1     1
     0     1    -1
     0     1     1
     0     0     0
     0     0     0
     0     0     0
```

Again, the repeated center point runs allow for a more uniform estimate of the prediction variance over the entire design space.

D-Optimal Designs

In this section...
“Introduction to D-Optimal Designs” on page 15-15
“Generate D-Optimal Designs” on page 15-16
“Augment D-Optimal Designs” on page 15-19
“Specify Fixed Covariate Factors” on page 15-20
“Specify Categorical Factors” on page 15-21
“Specify Candidate Sets” on page 15-21

Introduction to D-Optimal Designs

Traditional experimental designs (“Full Factorial Designs” on page 15-3, “Fractional Factorial Designs” on page 15-5, and “Response Surface Designs” on page 15-9) are appropriate for calibrating linear models in experimental settings where factors are relatively unconstrained in the region of interest. In some cases, however, models are necessarily nonlinear. In other cases, certain treatments (combinations of factor levels) may be expensive or infeasible to measure. *D-optimal designs* are model-specific designs that address these limitations of traditional designs.

A D-optimal design is generated by an iterative search algorithm and seeks to minimize the covariance of the parameter estimates for a specified model. This is equivalent to maximizing the determinant $D = |X^T X|$, where X is the design matrix of model terms (the columns) evaluated at specific treatments in the design space (the rows). Unlike traditional designs, D-optimal designs do not require orthogonal design matrices, and as a result, parameter estimates may be correlated. Parameter estimates may also be locally, but not globally, D-optimal.

There are several Statistics Toolbox functions for generating D-optimal designs:

Function	Description
candexch	Uses a row-exchange algorithm to generate a D-optimal design with a specified number of runs for a specified model and a specified candidate set. This is the second component of the algorithm used by rowexch.
candgen	Generates a candidate set for a specified model. This is the first component of the algorithm used by rowexch.
cordexch	Uses a coordinate-exchange algorithm to generate a D-optimal design with a specified number of runs for a specified model.
daugment	Uses a coordinate-exchange algorithm to augment an existing D-optimal design with additional runs to estimate additional model terms.
dcovary	Uses a coordinate-exchange algorithm to generate a D-optimal design with fixed covariate factors.
rowexch	Uses a row-exchange algorithm to generate a D-optimal design with a specified number of runs for a specified model. The algorithm calls candgen and then candexch. (Call candexch separately to specify a candidate set.)

The following sections explain how to use these functions to generate D-optimal designs.

Note The Statistics Toolbox function `rsmdemo` generates simulated data for experimental settings specified by either the user or by a D-optimal design generated by `cordexch`. It uses the `rstool` interface to visualize response surface models fit to the data, and it uses the `nlintool` interface to visualize a nonlinear model fit to the data.

Generate D-Optimal Designs

Two Statistics Toolbox algorithms generate D-optimal designs:

- The `cordexch` function uses a coordinate-exchange algorithm
- The `rowexch` function uses a row-exchange algorithm

Both `cordexch` and `rowexch` use iterative search algorithms. They operate by incrementally changing an initial design matrix X to increase $D = |X^T X|$ at each step. In both algorithms, there is randomness built into the selection of the initial design and into the choice of the incremental changes. As a result, both algorithms may return locally, but not globally, D-optimal designs. Run each algorithm multiple times and select the best result for your final design. Both functions have a 'tries' parameter that automates this repetition and comparison.

At each step, the row-exchange algorithm exchanges an entire row of X with a row from a design matrix C evaluated at a *candidate set* of feasible treatments. The `rowexch` function automatically generates a C appropriate for a specified model, operating in two steps by calling the `candgen` and `candexch` functions in sequence. Provide your own C by calling `candexch` directly. In either case, if C is large, its static presence in memory can affect computation.

The coordinate-exchange algorithm, by contrast, does not use a candidate set. (Or rather, the candidate set is the entire design space.) At each step, the coordinate-exchange algorithm exchanges a single element of X with a new element evaluated at a neighboring point in design space. The absence of a candidate set reduces demands on memory, but the smaller scale of the search means that the coordinate-exchange algorithm is more likely to become trapped in a local minimum than the row-exchange algorithm.

For example, suppose you want a design to estimate the parameters in the following three-factor, seven-term interaction model:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon$$

Use `cordexch` to generate a D-optimal design with seven runs:

```
nfactors = 3;
nruns = 7;
[dCE,X] = cordexch(nfactors,nruns,'interaction','tries',10)
dCE =
    -1     1     1
    -1    -1    -1
     1     1     1
    -1     1    -1
     1    -1     1
```

$$X = \begin{bmatrix}
 1 & -1 & -1 & & & & \\
 -1 & -1 & 1 & & & & \\
 1 & -1 & 1 & 1 & -1 & -1 & 1 \\
 1 & -1 & -1 & -1 & 1 & 1 & 1 \\
 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 1 & -1 & 1 & -1 & -1 & 1 & -1 \\
 1 & 1 & -1 & 1 & -1 & 1 & -1 \\
 1 & 1 & -1 & -1 & -1 & -1 & 1 \\
 1 & -1 & -1 & 1 & 1 & -1 & -1
 \end{bmatrix}$$

Columns of the design matrix X are the model terms evaluated at each row of the design dCE . The terms appear in order from left to right:

- 1** Constant term
- 2** Linear terms (1, 2, 3)
- 3** Interaction terms (12, 13, 23)

Use X in a linear regression model fit to response data measured at the design points in dCE .

Use `rowexch` in a similar fashion to generate an equivalent design:

```
[dRE,X] = rowexch(nfactors,nruns,'interaction','tries',10)
dRE =
```

$$\begin{bmatrix}
 -1 & -1 & 1 \\
 1 & -1 & 1 \\
 1 & -1 & -1 \\
 1 & 1 & 1 \\
 -1 & -1 & -1 \\
 -1 & 1 & -1 \\
 -1 & 1 & 1
 \end{bmatrix}$$

$$X = \begin{bmatrix}
 1 & -1 & -1 & 1 & 1 & -1 & -1 \\
 1 & 1 & -1 & 1 & -1 & 1 & -1 \\
 1 & 1 & -1 & -1 & -1 & -1 & 1 \\
 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
 1 & -1 & -1 & -1 & 1 & 1 & 1 \\
 1 & -1 & 1 & -1 & -1 & 1 & -1
 \end{bmatrix}$$


```
1 -1 1 1 -1 -1 1
```

Augment D-Optimal Designs

In practice, you may want to add runs to a completed experiment to learn more about a process and estimate additional model coefficients. The `daugment` function uses a coordinate-exchange algorithm to augment an existing D-optimal design.

For example, the following eight-run design is adequate for estimating main effects in a four-factor model:

```
dCEmain = cordexch(4,8)
dCEmain =
    1 -1 -1 1
   -1 -1 1 1
   -1 1 -1 1
    1 1 1 -1
    1 1 1 1
   -1 1 -1 -1
    1 -1 -1 -1
   -1 -1 1 -1
```

To estimate the six interaction terms in the model, augment the design with eight additional runs:

```
dCEinteraction = daugment(dCEmain,8,'interaction')
dCEinteraction =
    1 -1 -1 1
   -1 -1 1 1
   -1 1 -1 1
    1 1 1 -1
    1 1 1 1
   -1 1 -1 -1
    1 -1 -1 -1
   -1 -1 1 -1
   -1 1 1 1
   -1 -1 -1 -1
    1 -1 1 -1
    1 1 -1 1
   -1 1 1 -1
```

```

1      1      -1     -1
1      -1     1      1
1      1      1      -1

```

The augmented design is full factorial, with the original eight runs in the first eight rows.

The 'start' parameter of the `candexch` function provides the same functionality as `daugment`, but uses a row exchange algorithm rather than a coordinate-exchange algorithm.

Specify Fixed Covariate Factors

In many experimental settings, certain factors and their covariates are constrained to a fixed set of levels or combinations of levels. These cannot be varied when searching for an optimal design. The `dcovary` function allows you to specify fixed covariate factors in the coordinate exchange algorithm.

For example, suppose you want a design to estimate the parameters in a three-factor linear additive model, with eight runs that necessarily occur at different times. If the process experiences temporal linear drift, you may want to include the run time as a variable in the model. Produce the design as follows:

```

time = linspace(-1,1,8)';
[dCV,X] = dcovary(3,time,'linear')
dCV =
-1.0000    1.0000    1.0000   -1.0000
 1.0000   -1.0000   -1.0000   -0.7143
-1.0000   -1.0000   -1.0000   -0.4286
 1.0000   -1.0000    1.0000   -0.1429
 1.0000    1.0000   -1.0000    0.1429
-1.0000    1.0000   -1.0000    0.4286
 1.0000    1.0000    1.0000    0.7143
-1.0000   -1.0000    1.0000    1.0000
X =
 1.0000   -1.0000    1.0000    1.0000   -1.0000
 1.0000    1.0000   -1.0000   -1.0000   -0.7143
 1.0000   -1.0000   -1.0000   -1.0000   -0.4286
 1.0000    1.0000   -1.0000    1.0000   -0.1429

```

1.0000	1.0000	1.0000	-1.0000	0.1429
1.0000	-1.0000	1.0000	-1.0000	0.4286
1.0000	1.0000	1.0000	1.0000	0.7143
1.0000	-1.0000	-1.0000	1.0000	1.0000

The column vector `time` is a fixed factor, normalized to values between ± 1 . The number of rows in the fixed factor specifies the number of runs in the design. The resulting design `dCV` gives factor settings for the three controlled model factors at each time.

Specify Categorical Factors

Categorical factors take values in a discrete set of levels. Both `cordexch` and `rowexch` have a `'categorical'` parameter that allows you to specify the indices of categorical factors and a `'levels'` parameter that allows you to specify a number of levels for each factor.

For example, the following eight-run design is for a linear additive model with five factors in which the final factor is categorical with three levels:

```
dCEcat = cordexch(5,8,'linear','categorical',5,'levels',3)
dCEcat =
    -1    -1     1     1     2
    -1    -1    -1    -1     3
     1     1     1     1     3
     1     1    -1    -1     2
     1    -1    -1     1     3
    -1     1    -1     1     1
    -1     1     1    -1     3
     1    -1     1    -1     1
```

Specify Candidate Sets

The row-exchange algorithm exchanges rows of an initial design matrix X with rows from a design matrix C evaluated at a candidate set of feasible treatments. The `rowexch` function automatically generates a C appropriate for a specified model, operating in two steps by calling the `candgen` and `candexch` functions in sequence. Provide your own C by calling `candexch` directly.

For example, the following uses rowexch to generate a five-run design for a two-factor pure quadratic model using a candidate set that is produced internally:

```
dRE1 = rowexch(2,5,'purequadratic','tries',10)
dRE1 =
    -1     1
     0     0
     1    -1
     1     0
     1     1
```

The same thing can be done using candgen and candexch in sequence:

```
[dC,C] = candgen(2,'purequadratic') % Candidate set, C
dC =
    -1    -1
     0    -1
     1    -1
    -1     0
     0     0
     1     0
    -1     1
     0     1
     1     1
C =
     1    -1    -1     1     1
     1     0    -1     0     1
     1     1    -1     1     1
     1    -1     0     1     0
     1     0     0     0     0
     1     1     0     1     0
     1    -1     1     1     1
     1     0     1     0     1
     1     1     1     1     1
treatments = candexch(C,5,'tries',10) % D-opt subset
treatments =
     2
     1
     7
     3
```

```

      4
dRE2 = dC(treatments,:) % Display design
dRE2 =
      0     -1
     -1     -1
     -1      1
      1     -1
     -1      0

```

You can replace `C` in this example with a design matrix evaluated at your own candidate set. For example, suppose your experiment is constrained so that the two factors cannot have extreme settings simultaneously. The following produces a restricted candidate set:

```

constraint = sum(abs(dC),2) < 2; % Feasible treatments
my_dC = dC(constraint,:)
my_dC =
      0     -1
     -1      0
      0      0
      1      0
      0      1

```

Use the `x2fx` function to convert the candidate set to a design matrix:

```

my_C = x2fx(my_dC, 'purequadratic')
my_C =
      1      0     -1      0      1
      1     -1      0      1      0
      1      0      0      0      0
      1      1      0      1      0
      1      0      1      0      1

```

Find the required design in the same manner:

```

my_treatments = candexch(my_C,5,'tries',10) % D-opt subset
my_treatments =
      2
      4
      5
      1

```

```
      3
my_dRE = my_dC(my_treatments,:) % Display design
my_dRE =
    -1     0
     1     0
     0     1
     0    -1
     0     0
```

Statistical Process Control

- “Introduction to Statistical Process Control” on page 16-2
- “Control Charts” on page 16-3
- “Capability Studies” on page 16-6

Introduction to Statistical Process Control

Statistical process control (SPC) refers to a number of different methods for monitoring and assessing the quality of manufactured goods. Combined with methods from the design of experiments, SPC is used in programs that define, measure, analyze, improve, and control development and production processes. These programs are often implemented using “Design for Six Sigma” methodologies.

Control Charts

A control chart displays measurements of process samples over time. The measurements are plotted together with user-defined *specification limits* and process-defined *control limits*. The process can then be compared with its specifications—to see if it is *in control* or *out of control*.

The chart is just a monitoring tool. Control activity might occur if the chart indicates an undesirable, systematic change in the process. The control chart is used to discover the variation, so that the process can be adjusted to reduce it.

Control charts are created with the `controlchart` function. Any of the following chart types may be specified:

- Xbar or mean
- Standard deviation
- Range
- Exponentially weighted moving average
- Individual observation
- Moving range of individual observations
- Moving average of individual observations
- Proportion defective
- Number of defectives
- Defects per unit
- Count of defects

Control rules are specified with the `controlrules` function.

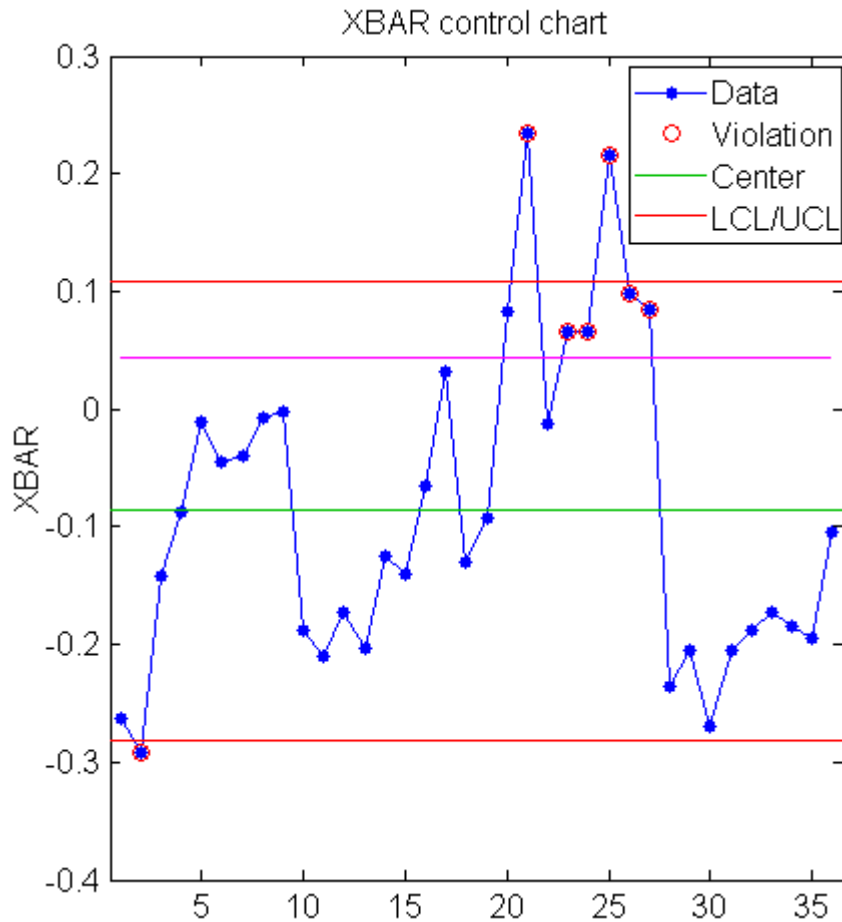
For example, the following commands create an xbar chart, using the “Western Electric 2” rule (2 of 3 points at least 2 standard errors above the center line) to mark out of control measurements:

```
load parts;  
st = controlchart(runout, 'rules', 'we2');
```

```

x = st.mean;
cl = st.mu;
se = st.sigma./sqrt(st.n);
hold on
plot(cl+2*se,'m')

```



Measurements that violate the control rule can then be identified:

```

R = controlrules('we2',x,cl,se);
I = find(R)

```

I =
21
23
24
25
26
27

Capability Studies

Before going into production, many manufacturers run a *capability study* to determine if their process will run within specifications enough of the time. *Capability indices* produced by such a study are used to estimate expected percentages of defective parts.

Capability studies are conducted with the `capability` function. The following capability indices are produced:

- `mu` — Sample mean
- `sigma` — Sample standard deviation
- `P` — Estimated probability of being within the lower (L) and upper (U) specification limits
- `P1` — Estimated probability of being below L
- `Pu` — Estimated probability of being above U
- `Cp` — $(U-L)/(6*\text{sigma})$
- `Cpl` — $(\text{mu}-L)/(3.*\text{sigma})$
- `Cpu` — $(U-\text{mu})/(3.*\text{sigma})$
- `Cpk` — $\min(\text{Cpl}, \text{Cpu})$

As an example, simulate a sample from a process with a mean of 3 and a standard deviation of 0.005:

```
data = normrnd(3,0.005,100,1);
```

Compute capability indices if the process has an upper specification limit of 3.01 and a lower specification limit of 2.99:

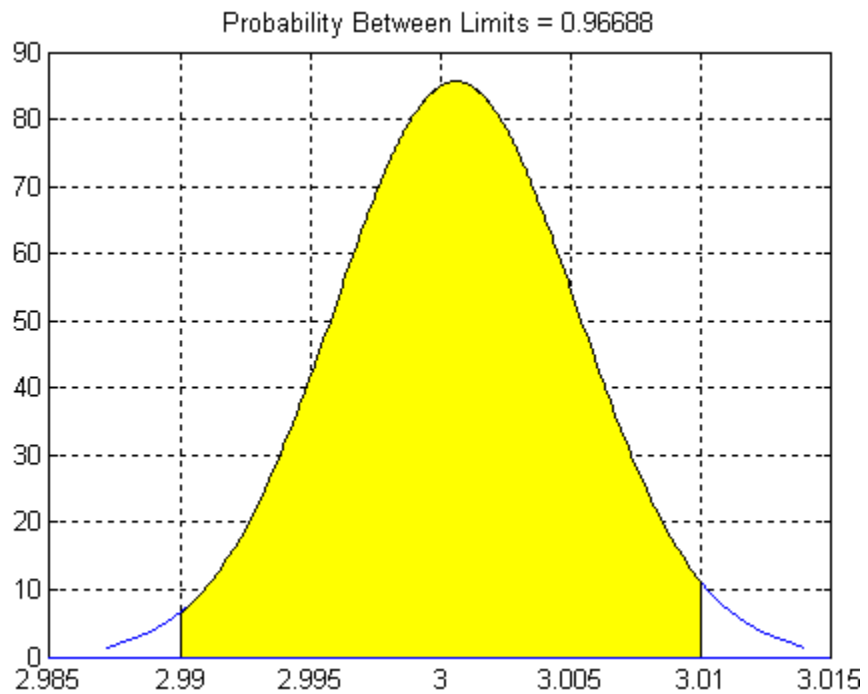
```
S = capability(data,[2.99 3.01])
```

```
S =
    mu: 3.0006
   sigma: 0.0047
      P: 0.9669
     P1: 0.0116
     Pu: 0.0215
```

Cp: 0.7156
Cp1: 0.7567
Cpu: 0.6744
Cpk: 0.6744

Visualize the specification and process widths:

```
capaplot(data,[2.99 3.01]);  
grid on
```



Parallel Statistics

- “Quick Start Parallel Computing for Statistics Toolbox” on page 17-2
- “Concepts of Parallel Computing in Statistics Toolbox” on page 17-7
- “When to Run Statistical Functions in Parallel” on page 17-8
- “Working with parfor” on page 17-10
- “Reproducibility in Parallel Statistical Computations” on page 17-13
- “Examples of Parallel Statistical Functions” on page 17-19

Quick Start Parallel Computing for Statistics Toolbox

Note To use parallel computing as described in this chapter, you must have a Parallel Computing Toolbox license.

In this section...
“What Is Parallel Statistics Functionality?” on page 17-2
“How To Compute in Parallel” on page 17-3
“Parallel Treebagger” on page 17-5

What Is Parallel Statistics Functionality?

You can use any of the Statistics Toolbox functions with Parallel Computing Toolbox constructs such as `parfor` and `spmd`. However, some functions, such as those with interactive displays, can lose functionality in parallel. In particular, displays and interactive usage are not effective on workers (see “Vocabulary for Parallel Computation” on page 17-7).

Additionally, the following functions are enhanced to use parallel computing internally. These functions use `parfor` internally to parallelize calculations.

- `bootci`
- `bootstrp`
- `candexch`
- `cordexch`
- `crossval`
- `daugment`
- `dcovary`
- `jackknife`
- `lasso`
- `lassoglm`

- `nmmf`
- `plsregress`
- `rowexch`
- `sequentialfs`
- `TreeBagger`
- `TreeBagger.growTrees`

This chapter gives the simplest way to use these enhanced functions in parallel. For more advanced topics, including the issues of reproducibility and nested `parfor` loops, see the other sections in this chapter.

For information on parallel statistical computing at the command line, enter
`help parallelstats`

How To Compute in Parallel

To have a function compute in parallel:

- 1 “Open `matlabpool`” on page 17-3
- 2 “Set the `UseParallel` Option to ‘always’” on page 17-5
- 3 “Call the Function Using the Options Structure” on page 17-5

Open `matlabpool`

To run a statistical computation in parallel, first set up a parallel environment.

Note Setting up a parallel environment can take several seconds.

Multicore. For a multicore machine, enter the following at the MATLAB command line:

```
matlabpool open n
```

n is the number of workers you want to use.

Network. If you have multiple processors on a network, use Parallel Computing Toolbox functions and MATLAB Distributed Computing Server™ software to establish parallel computation. Make sure that your system is configured properly for parallel computing.

Many parallel statistical functions call a function that can be one you define in a file. For example, `jackknife` calls a function (`jackfun`) that can be a built-in MATLAB function such as `corr`, but can also be a function you define. Built-in functions are available to all workers. However, you must take extra steps to enable workers to access a function file that you define.

To place a function file on the path of all workers, and check that it is accessible:

- 1 At the command line, enter

```
matlabpool open conf
```

or

```
matlabpool open conf n
```

where *conf* is your configuration, and *n* is the number of processors you want to use.

- 2 If *network_file_path* is the network path to your function file, enter

```
pctRunOnAll('addpath network_file_path')
```

so the worker processors can access your function file.

- 3 Check whether the file is on the path of every worker by entering:

```
pctRunOnAll('which filename')
```

If any worker does not have a path to the file, it reports:

```
filename not found.
```

Set the UseParallel Option to 'always'

Create an options structure with the `statset` function. To run in parallel, set the `UseParallel` option to 'always':

```
paroptions = statset('UseParallel','always');
```

Call the Function Using the Options Structure

Call your function with syntax that uses the options structure. For example:

```
% Run crossval in parallel
cvMse = crossval('mse',x,y,'predfun',regf,'Options',paroptions);

% Run bootstrp in parallel
sts = bootstrp(100,@(x)[mean(x) std(x)],y,'Options',paroptions);

% Run TreeBagger in parallel
b = TreeBagger(50,meas,spec,'OOBPred','on','Options',paroptions);
```

For more complete examples of parallel statistical functions, see “Parallel Treebagger” on page 17-5 and “Examples of Parallel Statistical Functions” on page 17-19.

After you have finished computing in parallel, close the parallel environment:

```
matlabpool close
```

Tip To save time, keep the pool open if you expect to compute in parallel again soon.

Parallel Treebagger

To run the example “Workflow Example: Regression of Insurance Risk Rating for Car Imports with TreeBagger” on page 13-120 in parallel:

- 1 Set up the parallel environment to use two cores:

```
matlabpool open 2
```

```
Starting matlabpool using the 'local' configuration ...
```

```
connected to 2 labs.
```

- 2 Set the options to use parallel processing:

```
paroptions = statset('UseParallel','always');
```

- 3 Load the problem data and separate it into input and response:

```
load imports-85;  
Y = X(:,1);  
X = X(:,2:end);
```

- 4 Estimate feature importance using leaf size 1 and 1000 trees in parallel. Time the function for comparison purposes:

```
tic  
b = TreeBagger(1000,X,Y,'Method','r','OOBVarImp','on',...  
    'cat',16:25,'MinLeaf',1,'Options',paroptions);  
toc
```

```
Elapsed time is 37.357930 seconds.
```

- 5 Perform the same computation in serial for timing comparison:

```
tic  
b = TreeBagger(1000,X,Y,'Method','r','OOBVarImp','on',...  
    'cat',16:25,'MinLeaf',1); % No options gives serial  
toc
```

```
Elapsed time is 63.921864 seconds.
```

Computing in parallel took less than 60% of the time of computing serially.

Concepts of Parallel Computing in Statistics Toolbox

In this section...

“Subtleties in Parallel Computing” on page 17-7

“Vocabulary for Parallel Computation” on page 17-7

Subtleties in Parallel Computing

There are two main subtleties in parallel computations:

- Nested parallel evaluations (see “No Nested parfor Loops” on page 17-11). Only the outermost parfor loop runs in parallel, the others run serially.
- Reproducible results when using random numbers (see “Reproducibility in Parallel Statistical Computations” on page 17-13). How can you get exactly the same results when repeatedly running a parallel computation that uses random numbers?

Vocabulary for Parallel Computation

- *worker* — An independent MATLAB session that runs code distributed by the *client*.
- *client* — The MATLAB session with which you interact, and that distributes jobs to workers.
- *parfor* — A Parallel Computing Toolbox function that distributes independent code segments to workers (see “Working with parfor” on page 17-10).
- *random stream* — A pseudorandom number generator, and the sequence of values it generates. MATLAB implements random streams with the `RandStream` class.
- *reproducible computation* — A computation that can be exactly replicated, even in the presence of random numbers (see “Reproducibility in Parallel Statistical Computations” on page 17-13).

When to Run Statistical Functions in Parallel

In this section...
“Why Run in Parallel?” on page 17-8
“Factors Affecting Speed” on page 17-8
“Factors Affecting Results” on page 17-9

Why Run in Parallel?

The main reason to run statistical computations in parallel is to gain speed, meaning to reduce the execution time of your program or functions. “Factors Affecting Speed” on page 17-8 discusses the main items affecting the speed of programs or functions. “Factors Affecting Results” on page 17-9 discusses details that can cause a parallel run to give different results than a serial run.

Factors Affecting Speed

Some factors that can affect the speed of execution of parallel processing are:

- Parallel environment setup. It takes time to run `matlabpool` to begin computing in parallel. If your computation is fast, the setup time can exceed any time saved by computing in parallel.
- Parallel overhead. There is overhead in communication and coordination when running in parallel. If function evaluations are fast, this overhead could be an appreciable part of the total computation time. Thus, solving a problem in parallel can be slower than solving the problem serially. For an example, see *Improving Optimization Performance with Parallel Computing* in *MATLAB Digest*, March 2009.
- No nested `parfor` loops. This is described in “Working with `parfor`” on page 17-10. `parfor` does not work in parallel when called from within another `parfor` loop. If you have programmed your custom functions to take advantage of parallel processing, the limitation of no nested `parfor` loops can cause a parallel function to run slower than expected.
- When executing serially, `parfor` loops run slightly slower than `for` loops.
- Passing parameters. Parameters are automatically passed to worker sessions during the execution of parallel computations. If there are many

parameters, or they take a large amount of memory, passing parameters can slow the execution of your computation.

- Contention for resources: network and computing. If the pool of workers has low bandwidth or high latency, parallel computation can be slow.

Factors Affecting Results

Some factors can affect results when using parallel processing. There are several caveats related to `parfor` listed in “Limitations” in the Parallel Computing Toolbox documentation. Some important factors are:

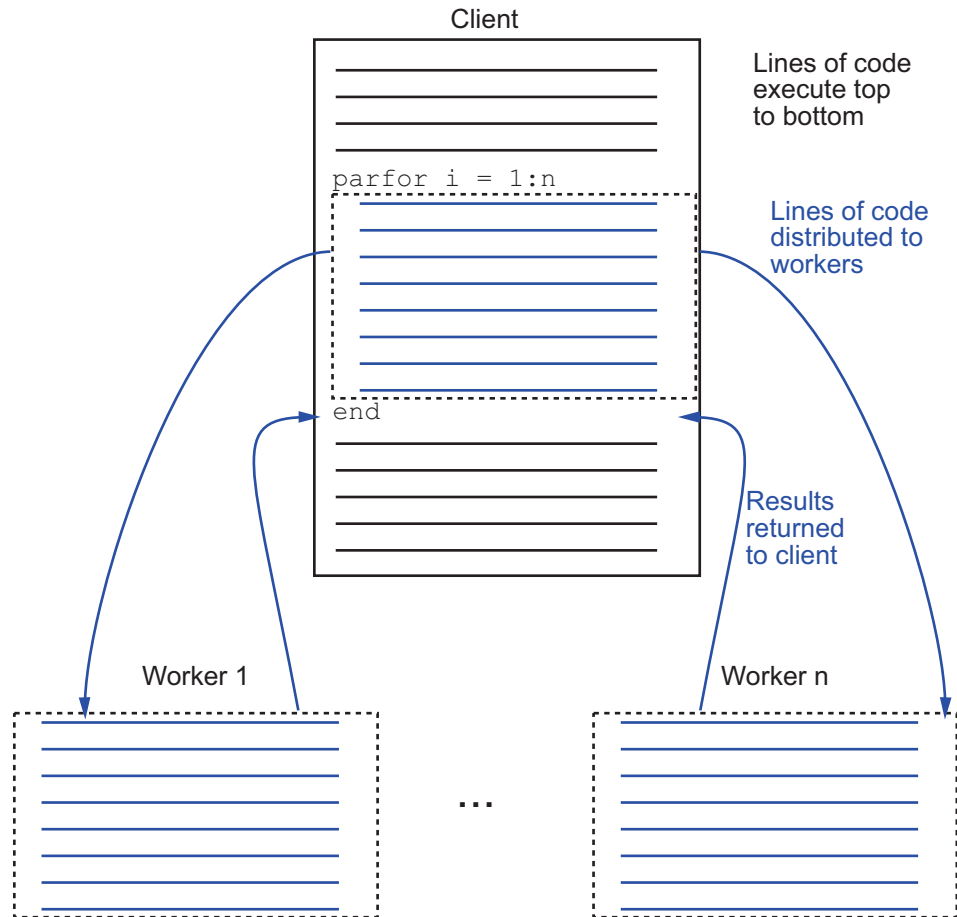
- Persistent or global variables. If any functions use persistent or global variables, these variables can take different values on different worker processors. Furthermore, they might not be cleared properly on the worker processors.
- Accessing external files. External files can be accessed unpredictably during a parallel computation. The order of computations is not guaranteed during parallel processing, so external files can be accessed in unpredictable order, leading to unpredictable results. Furthermore, if multiple processors try to read an external file simultaneously, the file can become locked, leading to a read error, and halting function execution.
- Noncomputational functions, such as `input`, `plot`, and `keyboard`, can behave badly when used in your custom functions. When called in a `parfor` loop, these functions are executed on worker machines. This can cause a worker to become nonresponsive, since it is waiting for input.
- `parfor` does not allow `break` or `return` statements.
- The random numbers you use can affect the results of your computations. See “Reproducibility in Parallel Statistical Computations” on page 17-13.

Working with parfor

In this section...
“How Statistical Functions Use parfor” on page 17-10
“Characteristics of parfor” on page 17-11

How Statistical Functions Use parfor

parfor is a Parallel Computing Toolbox function similar to a for loop. Parallel statistical functions call parfor internally. parfor distributes computations to worker processors.



Characteristics of parfor

More caveats related to `parfor` appear in “Limitations” in the Parallel Computing Toolbox documentation.

No Nested parfor Loops

`parfor` does not work in parallel when called from within another `parfor` loop, or from an `spmd` block. Parallelization occurs only at the outermost level.

Suppose, for example, you want to apply `jackknife` to your function `userfcn`, which calls `parfor`, and you want to call `jackknife` in a loop. The following figure shows three cases:

- 1** The outermost loop is `parfor`. Only that loop runs in parallel.
- 2** The outermost `parfor` loop is in `jackknife`. Only `jackknife` runs in parallel.
- 3** The outermost `parfor` loop is in `userfcn`. `userfcn` uses `parfor` in parallel.

Bold indicates the function that runs in parallel

① `...
parfor i=1:10
x(i)=jackknife(@userfcn,...)
...
end`
 Only the outermost `parfor` loop runs in parallel

② `...
for i=1:10
x(i)=jackknife(@userfcn,...)
...
end`
 If `UseParallel = 'always'` `jackknife` runs in parallel

③ `...
for i=1:10
x(i)=jackknife(@userfcn,...)
...
end`
 If `UseParallel = 'never'` `userfcn` can use `parfor` in parallel

When parfor Runs in Parallel

Reproducibility in Parallel Statistical Computations

In this section...

“Issues and Considerations in Reproducing Parallel Computations” on page 17-13

“Running Reproducible Parallel Computations” on page 17-14

“Parallel Statistical Computation Using Random Numbers” on page 17-15

Issues and Considerations in Reproducing Parallel Computations

A *reproducible* computation is one that gives the same results every time it runs. Reproducibility is important for:

- Debugging — To correct an anomalous result, you need to reproduce the result.
- Confidence — When you can reproduce results, you can investigate and understand them.
- Modifying existing code — When you change existing code, you want to ensure that you do not break anything.

Generally, you do not need to ensure reproducibility for your computation. Often, when you want reproducibility, the simplest technique is to run in serial instead of in parallel. In serial computation you can simply call the `rng` function as follows:

```
s = rng % Obtain the current state of the random stream
% run the statistical function
rng(s) % Reset the stream to the previous state
% run the statistical function again, obtain identical results
```

This section addresses the case when your function uses random numbers, and you want reproducible results in parallel. This section also addresses the case when you want the same results in parallel as in serial.

Running Reproducible Parallel Computations

To run a Statistics Toolbox function reproducibly:

- 1 Set the `UseSubstreams` option to `'always'`.
- 2 Set the `Streams` option to a type that supports substreams: `'mlfg6331_64'` or `'mrg32k3a'`. For information on these streams, see “Choosing a Random Number Generator” in the MATLAB Mathematics documentation.
- 3 To compute in parallel, set the `UseParallel` option to `'always'`.
- 4 Call the function with the options structure.
- 5 To reproduce the computation, reset the stream, then call the function again.

To understand why this technique gives reproducibility, see “How Substreams Enable Reproducible Parallel Computations” on page 17-15.

For example, to use the `'mlfg6331_64'` stream for reproducible computation:

- 1 Create an appropriate options structure:

```
s = RandStream('mlfg6331_64');
options = statset('UseParallel','always', ...
    'Streams',s,'UseSubstreams','always');
```
- 2 Run your parallel computation. For instructions, see “Quick Start Parallel Computing for Statistics Toolbox” on page 17-2.
- 3 Reset the random stream:

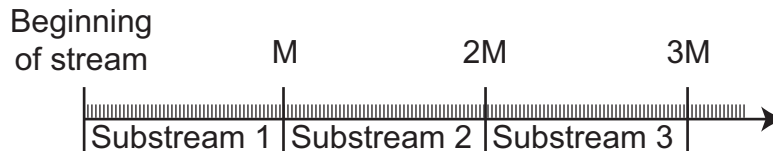
```
reset(s);
```
- 4 Rerun your parallel computation. You obtain identical results.

For an example of a parallel computation run this reproducible way, see “Reproducible Parallel Bootstrap” on page 17-23.

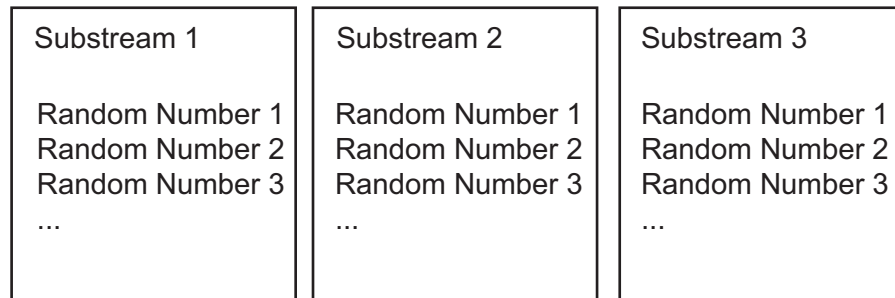
Parallel Statistical Computation Using Random Numbers

What Are Substreams?

A *substream* is a portion of a random stream that RandStream can access quickly. There is a number M such that for any positive integer k , RandStream can go the kM th pseudorandom number in the stream. From that point, RandStream can generate the subsequent entries in the stream. Currently, RandStream has $M = 2^{72}$, about $5e21$, or more.



The entries in different substreams have good statistical properties, similar to the properties of entries in a single stream: independence, and lack of k -way correlation at various lags. The substreams are so long that you can view the substreams as being independent streams, as in the following picture.



Two RandStream stream types support substreams: 'm1fg6331_64' and 'mrg32k3a'.

How Substreams Enable Reproducible Parallel Computations

When MATLAB performs computations in parallel with `parfor`, each worker receives loop iterations in an unpredictable order. Therefore, you cannot

predict which worker gets which iteration, so cannot determine the random numbers associated with each iteration.

Substreams allow MATLAB to tie each iteration to a particular sequence of random numbers. `parfor` gives each iteration an index. The iteration uses the index as the substream number. Since the random numbers are associated with the iterations, not with the workers, the entire computation is reproducible.

To obtain reproducible results, simply reset the stream, and all the substreams generate identical random numbers when called again. This method succeeds when all the workers use the same stream, and the stream supports substreams. This concludes the discussion of how the procedure in “Running Reproducible Parallel Computations” on page 17-14 gives reproducible parallel results.

Random Numbers on the Client or Workers

A few functions generate random numbers on the client before distributing them to parallel workers. The workers do not use random numbers, so operate purely deterministically. For these functions, you can run a parallel computation reproducibly using any random stream type.

The functions that operate this way include:

- `crossval`
- `plsregress`
- `sequentialfs`

To obtain identical results, reset the random stream on the client, or the random stream you pass to the client. For example:

```
s = rng % Obtain the current state of the random stream
% run the statistical function
rng(s) % Reset the stream to the previous state
% run the statistical function again, obtain identical results
```

While this method enables you to run reproducibly in parallel, the results can differ from a serial computation. The reason for the difference is `parfor` loops run in reverse order from `for` loops. Therefore, a serial computation can

generate random numbers in a different order than a parallel computation. For unequivocal reproducibility, use the technique in “Running Reproducible Parallel Computations” on page 17-14.

Distributing Streams Explicitly

For testing or comparison using particular random number algorithms, you must set the random number generators. How do you set these generators in parallel, or initialize streams on each worker in a particular way? Or you might want to run a computation using a different sequence of random numbers than any other you have run. How can you ensure the sequence you use is statistically independent?

Parallel Statistics Toolbox functions allow you to set random streams on each worker explicitly. For information on *creating* multiple streams, enter `help RandStream/create` at the command line. To create four independent streams using the 'mrg32k3a' generator:

```
s = RandStream.create('mrg32k3a', 'NumStreams', 4, ...
    'CellOutput', true);
```

Pass these streams to a statistical function using the Streams option. For example:

```
matlabpool open 4 % if you have at least 4 cores
s = RandStream.create('mrg32k3a', 'NumStreams', 4, ...
    'CellOutput', true); % create 4 independent streams
paroptions = statset('UseParallel', 'always', ...
    'Streams', s); % set the 4 different streams
x = [randn(700,1); 4 + 2*randn(300,1)];
latt = -4:0.01:12;
myfun = @(X) ksdensity(X, latt);
pdfestimate = myfun(x);
B = bootstrp(200, myfun, x, 'Options', paroptions);
```

See “Parallel Bootstrap” on page 17-21 for a plot of the results of this computation.

This method of distributing streams gives each worker a different stream for the computation. However, it does not allow for a reproducible computation, because the workers perform the 200 bootstraps in an unpredictable order. If

you want to perform a reproducible computation, use substreams as described in “Running Reproducible Parallel Computations” on page 17-14.

If you set the `UseSubstreams` option to `'always'`, then set the `Streams` option to a single random stream of the type that supports substreams (`'m1fg6331_64'` or `'mrg32k3a'`). This setting gives reproducible computations.

Examples of Parallel Statistical Functions

In this section...

“Parallel Jackknife” on page 17-19

“Parallel Cross Validation” on page 17-20

“Parallel Bootstrap” on page 17-21

Parallel Jackknife

This example is from the `jackknife` function reference page, but runs in parallel.

```
matlabpool open
opts = statset('UseParallel','always');
sigma = 5;
y = normrnd(0,sigma,100,1);
m = jackknife(@var, y,1,'Options',opts);
n = length(y);
bias = -sigma^2 / n % known bias formula
jbias = (n - 1)*(mean(m)-var(y,1)) % jackknife bias estimate

bias =
    -0.2500

jbias =
    -0.2698
```

This simple example is not a good candidate for parallel computation:

```
% How long to compute in serial?
tic;m = jackknife(@var,y,1);toc
Elapsed time is 0.023852 seconds.

% How long to compute in parallel?
tic;m = jackknife(@var,y,1,'Options',opts);toc
Elapsed time is 1.911936 seconds.
```

`jackknife` does not use random numbers, so gives the same results every time, whether run in parallel or serial.

Parallel Cross Validation

- “Simple Parallel Cross Validation” on page 17-20
- “Reproducible Parallel Cross Validation” on page 17-20

Simple Parallel Cross Validation

This example is the same as the first in the `crossval` function reference page, but runs in parallel.

```
matlabpool open
opts = statset('UseParallel','always');

load('fisheriris');
y = meas(:,1);
X = [ones(size(y,1),1),meas(:,2:4)];
regf=@(XTRAIN,ytrain,XTEST)(XTEST*regress(ytrain,XTRAIN));

cvMse = crossval('mse',X,y,'Predfun',regf,'Options',opts)

cvMse =
    0.0999
```

This simple example is not a good candidate for parallel computation:

```
% How long to compute in serial?
tic;cvMse = crossval('mse',X,y,'Predfun',regf);toc
Elapsed time is 0.046005 seconds.

% How long to compute in parallel?
tic;cvMse = crossval('mse',X,y,'Predfun',regf,...
    'Options',opts);toc
Elapsed time is 1.333021 seconds.
```

Reproducible Parallel Cross Validation

To run `crossval` in parallel in a reproducible fashion, set the options and reset the random stream appropriately (see “Running Reproducible Parallel Computations” on page 17-14).

```
matlabpool open
```

```
s = RandStream('mlfg6331_64');
options = statset('UseParallel','always',...
    'Streams',s,'UseSubstreams','always');

load('fisheriris');
y = meas(:,1);
X = [ones(size(y,1),1),meas(:,2:4)];
regf=@(XTRAIN,ytrain,XTEST)(XTEST*regress(ytrain,XTRAIN));

cvMse = crossval('mse',X,y,'Predfun',regf,'Options',opts)

cvMse =
    0.1020
```

Reset the stream and the result is identical:

```
reset(s)
cvMse = crossval('mse',X,y,'Predfun',regf,'Options',opts)

cvMse =
    0.1020
```

Parallel Bootstrap

- “Bootstrap in Serial and Parallel” on page 17-21
- “Reproducible Parallel Bootstrap” on page 17-23

Bootstrap in Serial and Parallel

Here is an example timing a bootstrap in parallel versus in serial. The example generates data from a mixture of two Gaussians, constructs a nonparametric estimate of the resulting data, and uses a bootstrap to get a sense of the sampling variability.

1 Generate the data:

```
% Generate a random sample of size 1000,
% from a mixture of two Gaussian distributions
x = [randn(700,1); 4 + 2*randn(300,1)];
```

2 Construct a nonparametric estimate of the density from the data:

```
latt = -4:0.01:12;  
myfun = @(X) ksdensity(X,latt);  
pdfestimate = myfun(x);
```

- 3** Bootstrap the estimate to get a sense of its sampling variability. Run the bootstrap in serial for timing comparison.

```
tic;B = bootstrp(200,myfun,x);toc
```

Elapsed time is 17.455586 seconds.

- 4** Run the bootstrap in parallel for timing comparison:

```
matlabpool open  
Starting matlabpool using the 'local' configuration ...  
connected to 2 labs.
```

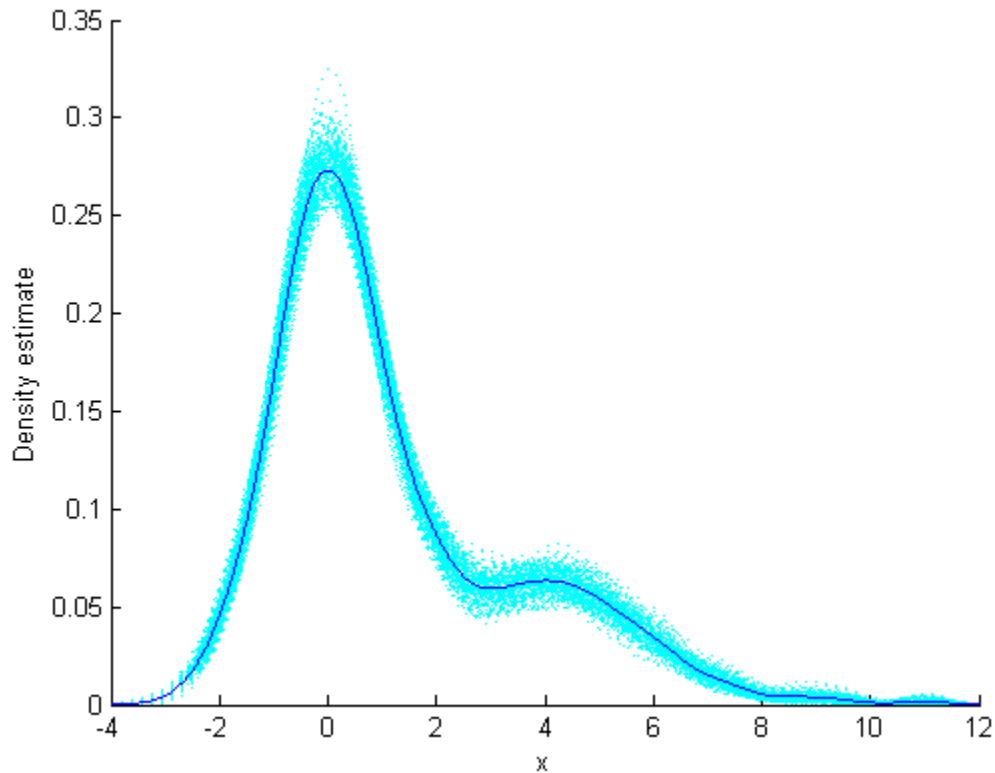
```
opt = statset('UseParallel','always');  
tic;B = bootstrp(200,myfun,x,'Options',opt);toc
```

Elapsed time is 9.984345 seconds.

Computing in parallel is nearly twice as fast as computing in serial for this example.

Overlay the `ksdensity` density estimate with the 200 bootstrapped estimates obtained in the parallel bootstrap. You can get a sense of how to assess the accuracy of the density estimate from this plot.

```
hold on  
for i=1:size(B,1),  
    plot(latt,B(i,:), 'c:')  
end  
plot(latt,pdfestimate);  
xlabel('x');ylabel('Density estimate')
```



Reproducible Parallel Bootstrap

To run the example in parallel in a reproducible fashion, set the options appropriately (see “Running Reproducible Parallel Computations” on page 17-14). First set up the problem and parallel environment as in “Bootstrap in Serial and Parallel” on page 17-21. Then set the options to use substreams along with a stream that supports substreams.

```
s = RandStream('mlfg6331_64'); % has substreams
opts = statset('UseParallel','always',...
    'Streams',s,'UseSubstreams','always');
B2 = bootstrp(200,myfun,x,'Options',opts);
```

To rerun the bootstrap and get the same result:

```
reset(s) % set the stream to initial state
B3 = bootstrp(200,myfun,x,'Options',opts);
isequal(B2,B3) % check if same results
```

```
ans =
     1
```

Function Reference

File I/O (p. 18-2)	Data file input/output
Data Organization (p. 18-3)	Data arrays and groups
Descriptive Statistics (p. 18-9)	Data summaries
Statistical Visualization (p. 18-12)	Data patterns and trends
Probability Distributions (p. 18-17)	Modeling data frequency
Hypothesis Tests (p. 18-33)	Inferences from data
Analysis of Variance (p. 18-35)	Modeling data variance
Parametric Regression Analysis (p. 18-36)	Continuous data models
Multivariate Methods (p. 18-42)	Visualization and reduction
Cluster Analysis (p. 18-45)	Identifying data categories
Model Assessment (p. 18-47)	Identifying data categories
Parametric Classification (p. 18-48)	Categorical data models
Nonparametric Supervised Learning (p. 18-51)	Classification and regression via trees, bagging, boosting, and more
Hidden Markov Models (p. 18-64)	Stochastic data models
Design of Experiments (p. 18-65)	Systematic data collection
Statistical Process Control (p. 18-69)	Production monitoring
GUIs (p. 18-70)	Interactive tools
Utilities (p. 18-71)	General purpose

File I/O

caseread	Read case names from file
casewrite	Write case names to file
tblread	Read tabular data from file
tblwrite	Write tabular data to file
tdfread	Read tab-delimited file
xptread	Create dataset array from data stored in SAS XPORT format file

Data Organization

Categorical Arrays (p. 18-3)

Dataset Arrays (p. 18-6)

Grouped Data (p. 18-8)

Categorical Arrays

addlevels (categorical)

Add levels to categorical array

cat (categorical)

Concatenate categorical arrays

categorical

Create categorical array

cellstr (categorical)

Convert categorical array to cell array of strings

char (categorical)

Convert categorical array to character array

circshift (categorical)

Shift categorical array circularly

ctranspose (categorical)

Transpose categorical matrix

double (categorical)

Convert categorical array to double array

droplevels (categorical)

Drop levels

end (categorical)

Last index in indexing expression for categorical array

flipdim (categorical)

Flip categorical array along specified dimension

fliplr (categorical)

Flip categorical matrix in left/right direction

flipud (categorical)

Flip categorical matrix in up/down direction

getlabels (categorical)

Access categorical array labels

getlevels (categorical)

Get categorical array levels

hist (categorical)	Plot histogram of categorical data
horzcat (categorical)	Horizontal concatenation for categorical arrays
int16 (categorical)	Convert categorical array to signed 16-bit integer array
int32 (categorical)	Convert categorical array to signed 32-bit integer array
int64 (categorical)	Convert categorical array to signed 64-bit integer array
int8 (categorical)	Convert categorical array to signed 8-bit integer array
intersect (categorical)	Set intersection for categorical arrays
ipermute (categorical)	Inverse permute dimensions of categorical array
isempty (categorical)	True for empty categorical array
isequal (categorical)	True if categorical arrays are equal
islevel (categorical)	Test for levels
ismember (categorical)	True for elements of categorical array in set
ismember (ordinal)	Test for membership
isscalar (categorical)	True if categorical array is scalar
isundefined (categorical)	Test for undefined elements
isvector (categorical)	True if categorical array is vector
length (categorical)	Length of categorical array
levelcounts (categorical)	Element counts by level
mergelevels (ordinal)	Merge levels
ndims (categorical)	Number of dimensions of categorical array
nominal	Construct nominal categorical array

numel (categorical)	Number of elements in categorical array
ordinal	Construct ordinal categorical array
permute (categorical)	Permute dimensions of categorical array
reorderlevels (categorical)	Reorder levels
repmat (categorical)	Replicate and tile categorical array
reshape (categorical)	Resize categorical array
rot90 (categorical)	Rotate categorical matrix 90 degrees
setdiff (categorical)	Set difference for categorical arrays
setlabels (categorical)	Label levels
setxor (categorical)	Set exclusive-or for categorical arrays
shiftdim (categorical)	Shift dimensions of categorical array
single (categorical)	Convert categorical array to single array
size (categorical)	Size of categorical array
sort (ordinal)	Sort elements of ordinal array
sortrows (ordinal)	Sort rows
squeeze (categorical)	Squeeze singleton dimensions from categorical array
summary (categorical)	Summary statistics for categorical array
times (categorical)	Product of categorical arrays
transpose (categorical)	Transpose categorical matrix
uint16 (categorical)	Convert categorical array to unsigned 16-bit integers
uint32 (categorical)	Convert categorical array to unsigned 32-bit integers

<code>uint64</code> (categorical)	Convert categorical array to unsigned 64-bit integers
<code>uint8</code> (categorical)	Convert categorical array to unsigned 8-bit integers
<code>union</code> (categorical)	Set union for categorical arrays
<code>unique</code> (categorical)	Unique values in categorical array
<code>vertcat</code> (categorical)	Vertical concatenation for categorical arrays

Dataset Arrays

<code>cat</code> (dataset)	Concatenate dataset arrays
<code>cell2dataset</code>	Convert cell array to dataset array
<code>cellstr</code> (dataset)	Create cell array of strings from dataset array
<code>dataset</code>	Construct dataset array
<code>dataset2cell</code> (dataset)	Convert dataset array to cell array
<code>dataset2struct</code> (dataset)	Convert dataset array to structure
<code>datasetfun</code> (dataset)	Apply function to dataset array variables
<code>double</code> (dataset)	Convert dataset variables to double array
<code>end</code> (dataset)	Last index in indexing expression for dataset array
<code>export</code> (dataset)	Write dataset array to file
<code>get</code> (dataset)	Access dataset array properties
<code>horzcat</code> (dataset)	Horizontal concatenation for dataset arrays
<code>intersect</code> (dataset)	Set intersection for dataset array observations

<code>isempty (dataset)</code>	True for empty dataset array
<code>ismember (dataset)</code>	Dataset array elements that are members of set
<code>ismissing (dataset)</code>	Find dataset array elements with missing values
<code>join (dataset)</code>	Merge observations
<code>length (dataset)</code>	Length of dataset array
<code>mat2dataset</code>	Convert matrix to dataset array
<code>ndims (dataset)</code>	Number of dimensions of dataset array
<code>numel (dataset)</code>	Number of elements in dataset array
<code>replacedata (dataset)</code>	Replace dataset variables
<code>replaceWithMissing (dataset)</code>	Insert missing data indicators into a dataset array
<code>set (dataset)</code>	Set and display properties
<code>setdiff (dataset)</code>	Set difference for dataset array observations
<code>setxor (dataset)</code>	Set exclusive or for dataset array observations
<code>single (dataset)</code>	Convert dataset variables to single array
<code>size (dataset)</code>	Size of dataset array
<code>sortrows (dataset)</code>	Sort rows of dataset array
<code>stack (dataset)</code>	Stack data from multiple variables into single variable
<code>struct2dataset</code>	Convert structure array to dataset array
<code>summary (dataset)</code>	Print summary of dataset array
<code>union (dataset)</code>	Set union for dataset array observations

unique (dataset)

Unique observations in dataset array

unstack (dataset)

Unstack data from single variable into multiple variables

vertcat (dataset)

Vertical concatenation for dataset arrays

Grouped Data

gplotmatrix

Matrix of scatter plots by group

grp2idx

Create index vector from grouping variable

grpstats

Summary statistics organized by group

gscatter

Scatter plot by group

Descriptive Statistics

Summaries (p. 18-9)

Measures of Central Tendency
(p. 18-9)

Measures of Dispersion (p. 18-9)

Measures of Shape (p. 18-10)

Statistics Resampling (p. 18-10)

Data with Missing Values (p. 18-10)

Data Correlation (p. 18-11)

Summaries

`crosstab`

Cross-tabulation

`grpstats`

Summary statistics organized by group

`summary` (categorical)

Summary statistics for categorical array

`tabulate`

Frequency table

Measures of Central Tendency

`geomean`

Geometric mean

`harmmean`

Harmonic mean

`trimmean`

Mean excluding outliers

Measures of Dispersion

`iqr`

Interquartile range

`mad`

Mean or median absolute deviation

moment
range

Central moments
Range of values

Measures of Shape

kurtosis
moment
skewness

Kurtosis
Central moments
Skewness

Statistics Resampling

bootci
bootstrp
jackknife

Bootstrap confidence interval
Bootstrap sampling
Jackknife sampling

Data with Missing Values

nancov
nanmax
nanmean
nanmedian
nanmin
nanstd
nansum
nanvar

Covariance ignoring NaN values
Maximum ignoring NaN values
Mean ignoring NaN values
Median ignoring NaN values
Minimum ignoring NaN values
Standard deviation ignoring NaN values
Sum ignoring NaN values
Variance, ignoring NaN values

Data Correlation

canoncorr	Canonical correlation
cholcov	Cholesky-like covariance decomposition
cophenet	Cophenetic correlation coefficient
corr	Linear or rank correlation
corrcov	Convert covariance matrix to correlation matrix
partialcorr	Linear or rank partial correlation coefficients
tiedrank	Rank adjusted for ties

Statistical Visualization

Distribution Plots (p. 18-12)

Scatter Plots (p. 18-13)

ANOVA Plots (p. 18-13)

Regression Plots (p. 18-14)

Multivariate Plots (p. 18-15)

Cluster Plots (p. 18-15)

Classification Plots (p. 18-16)

DOE Plots (p. 18-16)

SPC Plots (p. 18-16)

Distribution Plots

boxplot

Box plot

cdfplot

Empirical cumulative distribution function plot

dfittool

Interactive distribution fitting

disttool

Interactive density and distribution plots

ecdfhist

Empirical cumulative distribution function histogram

fsurfht

Interactive contour plot

hist3

Bivariate histogram

histfit

Histogram with a distribution fit

normplot

Normal probability plot

normspec

Normal density plot between specifications

probplot

Probability plots

qqplot

Quantile-quantile plot

randtool	Interactive random number generation
scatterhist	Scatter plot with marginal histograms
surfht	Interactive contour plot
wblplot	Weibull probability plot

Scatter Plots

gline	Interactively add line to plot
gname	Add case names to plot
gplotmatrix	Matrix of scatter plots by group
gscatter	Scatter plot by group
lsline	Add least-squares line to scatter plot
refcurve	Add reference curve to plot
refline	Add reference line to plot
scatterhist	Scatter plot with marginal histograms

ANOVA Plots

anova1	One-way analysis of variance
aoctool	Interactive analysis of covariance
manovacluster	Dendrogram of group mean clusters following MANOVA
multcompare	Multiple comparison test

Regression Plots

<code>addedvarplot</code>	Added variable plot
<code>gline</code>	Interactively add line to plot
<code>lassoPlot</code>	Trace plot of lasso fit
<code>lsline</code>	Add least-squares line to scatter plot
<code>plot (LinearModel)</code>	Scatter plot or added variable plot of linear model
<code>plotAdded (LinearModel)</code>	Added variable plot or leverage plot for linear model
<code>plotAdjustedResponse (LinearModel)</code>	Adjusted response plot for linear regression model
<code>plotDiagnostics (GeneralizedLinearModel)</code>	Plot diagnostics of generalized linear regression model
<code>plotDiagnostics (LinearModel)</code>	Plot diagnostics of linear regression model
<code>plotDiagnostics (NonLinearModel)</code>	Plot diagnostics of nonlinear regression model
<code>plotEffects (LinearModel)</code>	Plot main effects of each predictor in linear regression model
<code>plotInteraction (LinearModel)</code>	Plot interaction effects of two predictors in linear regression model
<code>plotResiduals (GeneralizedLinearModel)</code>	Plot residuals of generalized linear regression model
<code>plotResiduals (LinearModel)</code>	Plot residuals of linear regression model
<code>plotResiduals (NonLinearModel)</code>	Plot residuals of nonlinear regression model
<code>plotSlice (GeneralizedLinearModel)</code>	Plot of slices through fitted generalized linear regression surface
<code>plotSlice (LinearModel)</code>	Plot of slices through fitted linear regression surface

<code>plotSlice (NonLinearModel)</code>	Plot of slices through fitted nonlinear regression surface
<code>polytool</code>	Interactive polynomial fitting
<code>rcoplot</code>	Residual case order plot
<code>refcurve</code>	Add reference curve to plot
<code>refline</code>	Add reference line to plot
<code>robustdemo</code>	Interactive robust regression
<code>rsmdemo</code>	Interactive response surface demonstration
<code>rstool</code>	Interactive response surface modeling
<code>view (classregtree)</code>	Plot tree

Multivariate Plots

<code>andrewsplot</code>	Andrews plot
<code>biplot</code>	Biplot
<code>glyphplot</code>	Glyph plot
<code>parallelcoords</code>	Parallel coordinates plot

Cluster Plots

<code>dendrogram</code>	Dendrogram plot
<code>manovacluster</code>	Dendrogram of group mean clusters following MANOVA
<code>silhouette</code>	Silhouette plot

Classification Plots

perfcurve	Compute Receiver Operating Characteristic (ROC) curve or other performance curve for classifier output
view (classregtree)	Plot tree

DOE Plots

interactionplot	Interaction plot for grouped data
maineffectsplot	Main effects plot for grouped data
multivarichart	Multivari chart for grouped data
rsmdemo	Interactive response surface demonstration
rstool	Interactive response surface modeling

SPC Plots

capaplot	Process capability plot
controlchart	Shewhart control charts
histfit	Histogram with a distribution fit
normspec	Normal density plot between specifications

Probability Distributions

Distribution Objects (p. 18-17)
Distribution Plots (p. 18-18)
Probability Density (p. 18-19)
Cumulative Distribution (p. 18-21)
Inverse Cumulative Distribution
(p. 18-23)
Distribution Statistics (p. 18-25)
Distribution Fitting (p. 18-26)
Negative Log-Likelihood (p. 18-28)
Random Number Generators
(p. 18-28)
Quasi-Random Numbers (p. 18-30)
Piecewise Distributions (p. 18-31)

Distribution Objects

<code>cdf (ProbDist)</code>	Return cumulative distribution function (CDF) for ProbDist object
<code>fitdist</code>	Fit probability distribution to data
<code>icdf (ProbDistUnivKernel)</code>	Return inverse cumulative distribution function (ICDF) for ProbDistUnivKernel object
<code>icdf (ProbDistUnivParam)</code>	Return inverse cumulative distribution function (ICDF) for ProbDistUnivParam object
<code>iqr (ProbDistUnivKernel)</code>	Return interquartile range (IQR) for ProbDistUnivKernel object
<code>iqr (ProbDistUnivParam)</code>	Return interquartile range (IQR) for ProbDistUnivParam object

<code>mean (ProbDistUnivParam)</code>	Return mean of <code>ProbDistUnivParam</code> object
<code>median (ProbDistUnivKernel)</code>	Return median of <code>ProbDistUnivKernel</code> object
<code>median (ProbDistUnivParam)</code>	Return median of <code>ProbDistUnivParam</code> object
<code>paramci (ProbDistUnivParam)</code>	Return parameter confidence intervals of <code>ProbDistUnivParam</code> object
<code>pdf (ProbDist)</code>	Return probability density function (PDF) for <code>ProbDist</code> object
<code>ProbDistUnivKernel</code>	Construct <code>ProbDistUnivKernel</code> object
<code>ProbDistUnivParam</code>	Construct <code>ProbDistUnivParam</code> object
<code>random (ProbDist)</code>	Generate random number drawn from <code>ProbDist</code> object
<code>std (ProbDistUnivParam)</code>	Return standard deviation of <code>ProbDistUnivParam</code> object
<code>var (ProbDistUnivParam)</code>	Return variance of <code>ProbDistUnivParam</code> object

Distribution Plots

<code>boxplot</code>	Box plot
<code>cdfplot</code>	Empirical cumulative distribution function plot
<code>dfittool</code>	Interactive distribution fitting
<code>disttool</code>	Interactive density and distribution plots
<code>ecdfhist</code>	Empirical cumulative distribution function histogram

<code>fsurfht</code>	Interactive contour plot
<code>hist3</code>	Bivariate histogram
<code>histfit</code>	Histogram with a distribution fit
<code>normplot</code>	Normal probability plot
<code>normspec</code>	Normal density plot between specifications
<code>probplot</code>	Probability plots
<code>qqplot</code>	Quantile-quantile plot
<code>randtool</code>	Interactive random number generation
<code>scatterhist</code>	Scatter plot with marginal histograms
<code>surfht</code>	Interactive contour plot
<code>wblplot</code>	Weibull probability plot

Probability Density

<code>betapdf</code>	Beta probability density function
<code>binopdf</code>	Binomial probability density function
<code>chi2pdf</code>	Chi-square probability density function
<code>copulapdf</code>	Copula probability density function
<code>disttool</code>	Interactive density and distribution plots
<code>evpdf</code>	Extreme value probability density function
<code>exppdf</code>	Exponential probability density function
<code>fpdf</code>	F probability density function

<code>gampdf</code>	Gamma probability density function
<code>geopdf</code>	Geometric probability density function
<code>gevpdf</code>	Generalized extreme value probability density function
<code>gppdf</code>	Generalized Pareto probability density function
<code>hygepdf</code>	Hypergeometric probability density function
<code>ksdensity</code>	Kernel smoothing density estimate
<code>lognpdf</code>	Lognormal probability density function
<code>mnpdf</code>	Multinomial probability density function
<code>mvnpdf</code>	Multivariate normal probability density function
<code>mvtpdf</code>	Multivariate t probability density function
<code>nbinpdf</code>	Negative binomial probability density function
<code>ncfpdf</code>	Noncentral F probability density function
<code>nctpdf</code>	Noncentral t probability density function
<code>ncx2pdf</code>	Noncentral chi-square probability density function
<code>normpdf</code>	Normal probability density function
<code>pdf</code>	Probability density functions
<code>pdf (gmdistribution)</code>	Probability density function for Gaussian mixture distribution
<code>pdf (piecewisedistribution)</code>	Probability density function for piecewise distribution

poisspdf	Poisson probability density function
random (piecewisedistribution)	Random numbers from piecewise distribution
raylpdf	Rayleigh probability density function
tpdf	Student's t probability density function
unidpdf	Discrete uniform probability density function
unifpdf	Continuous uniform probability density function
wblpdf	Weibull probability density function

Cumulative Distribution

betacdf	Beta cumulative distribution function
binocdf	Binomial cumulative distribution function
cdf	Cumulative distribution functions
cdf (gmdistribution)	Cumulative distribution function for Gaussian mixture distribution
cdf (piecewisedistribution)	Cumulative distribution function for piecewise distribution
cdfplot	Empirical cumulative distribution function plot
chi2cdf	Chi-square cumulative distribution function
copulacdf	Copula cumulative distribution function
disttool	Interactive density and distribution plots

ecdf	Empirical cumulative distribution function
ecdfhist	Empirical cumulative distribution function histogram
evcdf	Extreme value cumulative distribution function
expcdf	Exponential cumulative distribution function
fcdf	F cumulative distribution function
gamedf	Gamma cumulative distribution function
geocdf	Geometric cumulative distribution function
gevcdf	Generalized extreme value cumulative distribution function
gpcdf	Generalized Pareto cumulative distribution function
hygecdf	Hypergeometric cumulative distribution function
logncdf	Lognormal cumulative distribution function
mvncdf	Multivariate normal cumulative distribution function
mvtcdf	Multivariate t cumulative distribution function
ncfcdf	Noncentral F cumulative distribution function
nctcdf	Noncentral t cumulative distribution function
ncx2cdf	Noncentral chi-square cumulative distribution function

normcdf	Normal cumulative distribution function
poisscdf	Poisson cumulative distribution function
raylcdf	Rayleigh cumulative distribution function
tcdf	Student's t cumulative distribution function
unidcdf	Discrete uniform cumulative distribution function
unifcdf	Continuous uniform cumulative distribution function
wblcdf	Weibull cumulative distribution function

Inverse Cumulative Distribution

betainv	Beta inverse cumulative distribution function
binoinv	Binomial inverse cumulative distribution function
chi2inv	Chi-square inverse cumulative distribution function
evinv	Extreme value inverse cumulative distribution function
expinv	Exponential inverse cumulative distribution function
finv	F inverse cumulative distribution function
gaminv	Gamma inverse cumulative distribution function

geoinv	Geometric inverse cumulative distribution function
gevinv	Generalized extreme value inverse cumulative distribution function
gpinv	Generalized Pareto inverse cumulative distribution function
hygeinv	Hypergeometric inverse cumulative distribution function
icdf	Inverse cumulative distribution functions
icdf (piecewisedistribution)	Inverse cumulative distribution function for piecewise distribution
logninv	Lognormal inverse cumulative distribution function
nbininv	Negative binomial inverse cumulative distribution function
ncfinv	Noncentral F inverse cumulative distribution function
nctinv	Noncentral t inverse cumulative distribution function
ncx2inv	Noncentral chi-square inverse cumulative distribution function
norminv	Normal inverse cumulative distribution function
poissinv	Poisson inverse cumulative distribution function
raylinv	Rayleigh inverse cumulative distribution function
tin	Student's t inverse cumulative distribution function
unidinv	Discrete uniform inverse cumulative distribution function

unifinv	Continuous uniform inverse cumulative distribution function
wblinv	Weibull inverse cumulative distribution function

Distribution Statistics

betastat	Beta mean and variance
binostat	Binomial mean and variance
chi2stat	Chi-square mean and variance
copulastat	Copula rank correlation
evstat	Extreme value mean and variance
expstat	Exponential mean and variance
fstat	F mean and variance
gamstat	Gamma mean and variance
geostat	Geometric mean and variance
gevstat	Generalized extreme value mean and variance
gpstat	Generalized Pareto mean and variance
hygestat	Hypergeometric mean and variance
lognstat	Lognormal mean and variance
nbinstat	Negative binomial mean and variance
ncfstat	Noncentral F mean and variance
nctstat	Noncentral t mean and variance
ncx2stat	Noncentral chi-square mean and variance
normstat	Normal mean and variance
poisstat	Poisson mean and variance

raylstat	Rayleigh mean and variance
tstat	Student's t mean and variance
unidstat	Discrete uniform mean and variance
unifstat	Continuous uniform mean and variance
wblstat	Weibull mean and variance

Distribution Fitting

Supported Distributions (p. 18-26)

Piecewise Distributions (p. 18-27)

Supported Distributions

betafit	Beta parameter estimates
binofit	Binomial parameter estimates
copulafit	Fit copula to data
copulaparam	Copula parameters as function of rank correlation
dfittool	Interactive distribution fitting
evfit	Extreme value parameter estimates
expfit	Exponential parameter estimates
fit (gmdistribution)	Gaussian mixture parameter estimates
gamfit	Gamma parameter estimates
gevfit	Generalized extreme value parameter estimates
gpfif	Generalized Pareto parameter estimates
histfit	Histogram with a distribution fit

johnsrnd	Johnson system random numbers
lognfit	Lognormal parameter estimates
mle	Maximum likelihood estimates
mlecov	Asymptotic covariance of maximum likelihood estimators
nbinfid	Negative binomial parameter estimates
normfit	Normal parameter estimates
normplot	Normal probability plot
pearsrnd	Pearson system random numbers
poissfit	Poisson parameter estimates
raylfit	Rayleigh parameter estimates
unifit	Continuous uniform parameter estimates
wblfit	Weibull parameter estimates
wblplot	Weibull probability plot

Piecewise Distributions

boundary (piecewisedistribution)	Piecewise distribution boundaries
lowerparams (paretotails)	Lower Pareto tails parameters
nsegments (piecewisedistribution)	Number of segments
paretotails	Construct Pareto tails object
piecewisedistribution	Create piecewise distribution object
segment (piecewisedistribution)	Segments containing values
upperparams (paretotails)	Upper Pareto tails parameters

Negative Log-Likelihood

betalike	Beta negative log-likelihood
evlike	Extreme value negative log-likelihood
explike	Exponential negative log-likelihood
gamlike	Gamma negative log-likelihood
gevlike	Generalized extreme value negative log-likelihood
gplike	Generalized Pareto negative log-likelihood
lognlike	Lognormal negative log-likelihood
mvregresslike	Negative log-likelihood for multivariate regression
normlike	Normal negative log-likelihood
wbllike	Weibull negative log-likelihood

Random Number Generators

betarnd	Beta random numbers
binornd	Binomial random numbers
chi2rnd	Chi-square random numbers
copularnd	Copula random numbers
datasample	Randomly sample from data, with or without replacement
evrnd	Extreme value random numbers
exprnd	Exponential random numbers
frnd	<i>F</i> random numbers
gamrnd	Gamma random numbers
geornd	Geometric random numbers

gevrnd	Generalized extreme value random numbers
gprnd	Generalized Pareto random numbers
hygernd	Hypergeometric random numbers
iwishrnd	Inverse Wishart random numbers
johnsrnd	Johnson system random numbers
lhsdesign	Latin hypercube sample
lhsnorm	Latin hypercube sample from normal distribution
lognrnd	Lognormal random numbers
mhsample	Metropolis-Hastings sample
mnrnd	Multinomial random numbers
mvnrnd	Multivariate normal random numbers
mvtrnd	Multivariate t random numbers
nbinrnd	Negative binomial random numbers
ncfrnd	Noncentral F random numbers
nctrnd	Noncentral t random numbers
ncx2rnd	Noncentral chi-square random numbers
normrnd	Normal random numbers
pearsrnd	Pearson system random numbers
poissrnd	Poisson random numbers
randg	Gamma random numbers with unit scale
random	Random numbers
random (gmdistribution)	Random numbers from Gaussian mixture distribution

random (piecewisedistribution)	Random numbers from piecewise distribution
randsample	Random sample
randtool	Interactive random number generation
raylrnd	Rayleigh random numbers
slicesample	Slice sampler
trnd	Student's t random numbers
unidrnd	Discrete uniform random numbers
unifrnd	Continuous uniform random numbers
wblrnd	Weibull random numbers
wishrnd	Wishart random numbers

Quasi-Random Numbers

addlistener (qrandstream)	Add listener for event
delete (qrandstream)	Delete handle object
end (qrandset)	Last index in indexing expression for point set
eq (qrandstream)	Test handle equality
findobj (qrandstream)	Find objects matching specified conditions
findprop (qrandstream)	Find property of MATLAB handle object
ge (qrandstream)	Greater than or equal relation for handles
gt (qrandstream)	Greater than relation for handles
haltonset	Construct Halton quasi-random point set

<code>isvalid (qgrandstream)</code>	Test handle validity
<code>le (qgrandstream)</code>	Less than or equal relation for handles
<code>length (qgrandset)</code>	Length of point set
<code>lt (qgrandstream)</code>	Less than relation for handles
<code>ndims (qgrandset)</code>	Number of dimensions in matrix
<code>ne (qgrandstream)</code>	Not equal relation for handles
<code>net (qgrandset)</code>	Generate quasi-random point set
<code>notify (qgrandstream)</code>	Notify listeners of event
<code>qgrand (qgrandstream)</code>	Generate quasi-random points from stream
<code>qgrandset</code>	Abstract quasi-random point set class
<code>qgrandstream</code>	Construct quasi-random number stream
<code>rand (qgrandstream)</code>	Generate quasi-random points from stream
<code>reset (qgrandstream)</code>	Reset state
<code>scramble (qgrandset)</code>	Scramble quasi-random point set
<code>size (qgrandset)</code>	Number of dimensions in matrix
<code>sobolset</code>	Construct Sobol quasi-random point set

Piecewise Distributions

<code>boundary (piecewisedistribution)</code>	Piecewise distribution boundaries
<code>cdf (piecewisedistribution)</code>	Cumulative distribution function for piecewise distribution
<code>icdf (piecewisedistribution)</code>	Inverse cumulative distribution function for piecewise distribution

lowerparams (paretotails)	Lower Pareto tails parameters
nsegments (piecewisedistribution)	Number of segments
paretotails	Construct Pareto tails object
pdf (piecewisedistribution)	Probability density function for piecewise distribution
piecewisedistribution	Create piecewise distribution object
random (piecewisedistribution)	Random numbers from piecewise distribution
segment (piecewisedistribution)	Segments containing values
upperparams (paretotails)	Upper Pareto tails parameters

Hypothesis Tests

ansaribradley	Ansari-Bradley test
barttest	Bartlett's test
canoncorr	Canonical correlation
chi2gof	Chi-square goodness-of-fit test
dwtest	Durbin-Watson test
friedman	Friedman's test
jbtest	Jarque-Bera test
kruskalwallis	Kruskal-Wallis test
kstest	One-sample Kolmogorov-Smirnov test
kstest2	Two-sample Kolmogorov-Smirnov test
lillietest	Lilliefors test
linhypstest	Linear hypothesis test
ranksum	Wilcoxon rank sum test
runstest	Run test for randomness
sampsizepwr	Sample size and power of test
signrank	Wilcoxon signed rank test
signtest	Sign test
ttest	One-sample and paired-sample t -test
ttest2	Two-sample t -test
vartest	Chi-square variance test
vartest2	Two-sample F -test for equal variances
vartestn	Bartlett multiple-sample test for equal variances

zscore

ztest

Standardized z -scores

z -test

Analysis of Variance

ANOVA Plots (p. 18-35)

ANOVA Operations (p. 18-35)

ANOVA Plots

anova1	One-way analysis of variance
aoctool	Interactive analysis of covariance
manovacluster	Dendrogram of group mean clusters following MANOVA
multcompare	Multiple comparison test

ANOVA Operations

anova (LinearModel)	Analysis of variance for linear model
anova1	One-way analysis of variance
anova2	Two-way analysis of variance
anovan	<i>N</i> -way analysis of variance
aoctool	Interactive analysis of covariance
dummyvar	Create dummy variables
friedman	Friedman's test
kruskalwallis	Kruskal-Wallis test
manova1	One-way multivariate analysis of variance
manovacluster	Dendrogram of group mean clusters following MANOVA
multcompare	Multiple comparison test

Parametric Regression Analysis

Regression Plots (p. 18-36)

Linear Regression (p. 18-37)

Generalized Linear Regression
(p. 18-39)

Nonlinear Regression (p. 18-40)

Regression Plots

addedvarplot

Added variable plot

gline

Interactively add line to plot

lassoPlot

Trace plot of lasso fit

lsline

Add least-squares line to scatter plot

plot (LinearModel)

Scatter plot or added variable plot of linear model

plotAdded (LinearModel)

Added variable plot or leverage plot for linear model

plotAdjustedResponse
(LinearModel)

Adjusted response plot for linear regression model

plotDiagnostics
(GeneralizedLinearModel)

Plot diagnostics of generalized linear regression model

plotDiagnostics (LinearModel)

Plot diagnostics of linear regression model

plotDiagnostics (NonLinearModel)

Plot diagnostics of nonlinear regression model

plotEffects (LinearModel)

Plot main effects of each predictor in linear regression model

plotInteraction (LinearModel)

Plot interaction effects of two predictors in linear regression model

<code>plotResiduals</code> (<code>GeneralizedLinearModel</code>)	Plot residuals of generalized linear regression model
<code>plotResiduals</code> (<code>LinearModel</code>)	Plot residuals of linear regression model
<code>plotResiduals</code> (<code>NonLinearModel</code>)	Plot residuals of nonlinear regression model
<code>plotSlice</code> (<code>GeneralizedLinearModel</code>)	Plot of slices through fitted generalized linear regression surface
<code>plotSlice</code> (<code>LinearModel</code>)	Plot of slices through fitted linear regression surface
<code>plotSlice</code> (<code>NonLinearModel</code>)	Plot of slices through fitted nonlinear regression surface
<code>polytool</code>	Interactive polynomial fitting
<code>rcoplot</code>	Residual case order plot
<code>refcurve</code>	Add reference curve to plot
<code>refline</code>	Add reference line to plot
<code>robustdemo</code>	Interactive robust regression
<code>rsmdemo</code>	Interactive response surface demonstration
<code>rstool</code>	Interactive response surface modeling
<code>view</code> (<code>classregtree</code>)	Plot tree

Linear Regression

<code>addTerms</code> (<code>LinearModel</code>)	Add terms to linear regression model
<code>anova</code> (<code>LinearModel</code>)	Analysis of variance for linear model
<code>coefCI</code> (<code>LinearModel</code>)	Confidence intervals of coefficient estimates of linear model
<code>coefTest</code> (<code>LinearModel</code>)	Linear hypothesis test on linear regression model coefficients

<code>coxphfit</code>	Cox proportional hazards regression
<code>disp (LinearModel)</code>	Display linear regression model
<code>dummyvar</code>	Create dummy variables
<code>dwttest (LinearModel)</code>	Durbin-Watson test of linear model
<code>feval (LinearModel)</code>	Evaluate linear regression model prediction
<code>fit (LinearModel)</code>	Create linear regression model
<code>invpred</code>	Inverse prediction
<code>lasso</code>	Regularized least-squares regression using lasso or elastic net algorithms
<code>leverage</code>	Leverage
<code>LinearModel</code>	Linear regression model class
<code>mnrfit</code>	Multinomial logistic regression
<code>mnrval</code>	Multinomial logistic regression values
<code>mvregress</code>	Multivariate linear regression
<code>mvregresslike</code>	Negative log-likelihood for multivariate regression
<code>plsregress</code>	Partial least-squares regression
<code>polyconf</code>	Polynomial confidence intervals
<code>polytool</code>	Interactive polynomial fitting
<code>predict (LinearModel)</code>	Predict response of linear regression model
<code>random (LinearModel)</code>	Simulate responses for linear regression model
<code>regress</code>	Multiple linear regression
<code>regstats</code>	Regression diagnostics
<code>removeTerms (LinearModel)</code>	Remove terms from linear model
<code>ridge</code>	Ridge regression

<code>robustdemo</code>	Interactive robust regression
<code>robustfit</code>	Robust regression
<code>rsmdemo</code>	Interactive response surface demonstration
<code>rstool</code>	Interactive response surface modeling
<code>step (LinearModel)</code>	Improve linear regression model by adding or removing terms
<code>stepwise</code>	Interactive stepwise regression
<code>stepwise (LinearModel)</code>	Create linear regression model by stepwise regression
<code>stepwisefit</code>	Stepwise regression
<code>x2fx</code>	Convert predictor matrix to design matrix

Generalized Linear Regression

<code>addTerms (GeneralizedLinearModel)</code>	Add terms to generalized linear model
<code>coefCI (GeneralizedLinearModel)</code>	Confidence intervals of coefficient estimates of generalized linear model
<code>coefTest (GeneralizedLinearModel)</code>	Linear hypothesis test on generalized linear regression model coefficients
<code>devianceTest (GeneralizedLinearModel)</code>	Analysis of deviance
<code>disp (GeneralizedLinearModel)</code>	Display generalized linear regression model
<code>feval (GeneralizedLinearModel)</code>	Evaluate generalized linear regression model prediction
<code>fit (GeneralizedLinearModel)</code>	Create generalized linear regression model

GeneralizedLinearModel	Generalized linear regression model class
glmfit	Generalized linear model regression
glmval	Generalized linear model values
lassoglm	Lasso or elastic net regularization for generalized linear model regression
predict (GeneralizedLinearModel)	Predict response of generalized linear regression model
random (GeneralizedLinearModel)	Simulate responses for generalized linear regression model
removeTerms (GeneralizedLinearModel)	Remove terms from generalized linear model
step (GeneralizedLinearModel)	Improve generalized linear regression model by adding or removing terms
stepwise (GeneralizedLinearModel)	Create generalized linear regression model by stepwise regression

Nonlinear Regression

coefCI (NonLinearModel)	Confidence intervals of coefficient estimates of nonlinear regression model
coefTest (NonLinearModel)	Linear hypothesis test on nonlinear regression model coefficients
disp (NonLinearModel)	Display nonlinear regression model
dummyvar	Create dummy variables
feval (NonLinearModel)	Evaluate nonlinear regression model prediction
fit (NonLinearModel)	Fit nonlinear regression model
hougen	Hougen-Watson model

<code>nlinfit</code>	Nonlinear regression
<code>nlintool</code>	Interactive nonlinear regression
<code>nlmefit</code>	Nonlinear mixed-effects estimation
<code>nlmefitsa</code>	Fit nonlinear mixed-effects model with stochastic EM algorithm
<code>nlparci</code>	Nonlinear regression parameter confidence intervals
<code>nlpredci</code>	Nonlinear regression prediction confidence intervals
<code>NonLinearModel</code>	Nonlinear regression model class
<code>predict (NonLinearModel)</code>	Predict response of nonlinear regression model
<code>random (NonLinearModel)</code>	Simulate responses for nonlinear regression model

Multivariate Methods

Multivariate Plots (p. 18-42)

Multidimensional Scaling (p. 18-42)

Procrustes Analysis (p. 18-42)

Feature Selection (p. 18-43)

Feature Transformation (p. 18-43)

Multivariate Plots

andrewsplot

Andrews plot

biplot

Biplot

glyphplot

Glyph plot

parallelcoords

Parallel coordinates plot

Multidimensional Scaling

cmdscale

Classical multidimensional scaling

mahal

Mahalanobis distance

mdscale

Nonclassical multidimensional scaling

pdist

Pairwise distance between pairs of objects

squareform

Format distance matrix

Procrustes Analysis

procrustes

Procrustes analysis

Feature Selection

sequentialfs

Sequential feature selection

Feature Transformation

Nonnegative Matrix Factorization
(p. 18-43)

Principal Component Analysis
(p. 18-43)

Factor Analysis (p. 18-44)

Nonnegative Matrix Factorization

nnmf

Nonnegative matrix factorization

Principal Component Analysis

barttest

Bartlett's test

pca

Principal component analysis of raw data

pcacov

Principal component analysis on covariance matrix

pcares

Residuals from principal component analysis

princomp

Principal component analysis (PCA) on data

rotatefactors

Rotate factor loadings

Factor Analysis

factoran

Factor analysis

rotatefactors

Rotate factor loadings

Cluster Analysis

Cluster Plots (p. 18-45)

Hierarchical Clustering (p. 18-45)

K-Means Clustering (p. 18-46)

Gaussian Mixture Models (p. 18-46)

Cluster Plots

dendrogram

Dendrogram plot

manovacluster

Dendrogram of group mean clusters following MANOVA

silhouette

Silhouette plot

Hierarchical Clustering

cluster

Construct agglomerative clusters from linkages

clusterdata

Agglomerative clusters from data

cophenet

Cophenetic correlation coefficient

inconsistent

Inconsistency coefficient

linkage

Agglomerative hierarchical cluster tree

pdist

Pairwise distance between pairs of objects

squareform

Format distance matrix

K-Means Clustering

kmeans	<i>K</i> -means clustering
mahal	Mahalanobis distance

Gaussian Mixture Models

cdf (gmdistribution)	Cumulative distribution function for Gaussian mixture distribution
cluster (gmdistribution)	Construct clusters from Gaussian mixture distribution
fit (gmdistribution)	Gaussian mixture parameter estimates
gmdistribution	Construct Gaussian mixture distribution
mahal (gmdistribution)	Mahalanobis distance to component means
pdf (gmdistribution)	Probability density function for Gaussian mixture distribution
posterior (gmdistribution)	Posterior probabilities of components
random (gmdistribution)	Random numbers from Gaussian mixture distribution

Model Assessment

`confusionmat`

Confusion matrix

`crossval`

Loss estimate using cross validation

`cvpartition`

Create cross validation partition for data

`repartition (cvpartition)`

Repartition data for cross-validation

`test (cvpartition)`

Test indices for cross-validation

`training (cvpartition)`

Training indices for cross-validation

Parametric Classification

Discriminant Analysis (p. 18-48)

Naive Bayes Classification (p. 18-49)

Classification Plots (p. 18-50)

Discriminant Analysis

ClassificationDiscriminant	Discriminant analysis classification
ClassificationPartitionedModel	Cross-validated classification model
classify	Discriminant analysis
compact (ClassificationDiscriminant)	Compact discriminant analysis classifier
CompactClassificationDiscriminant	Compact discriminant analysis class
crossval (ClassificationDiscriminant)	Cross-validated discriminant analysis classifier
cvshrink (ClassificationDiscriminant)	Cross-validate regularization of linear discriminant
edge (CompactClassificationDiscriminant)	Classification edge
fit (ClassificationDiscriminant)	Fit discriminant analysis classifier
kfoldEdge (ClassificationPartitionedModel)	Classification edge for observations not used for training
kfoldfun (ClassificationPartitionedModel)	Cross validate function
kfoldLoss (ClassificationPartitionedModel)	Classification loss for observations not used for training
kfoldMargin (ClassificationPartitionedModel)	Classification margins for observations not used for training
kfoldPredict (ClassificationPartitionedModel)	Predict response for observations not used for training

logP (CompactClassificationDiscriminant)	Log of the unconditional probability density
loss (CompactClassificationDiscriminant)	Classification error
mahal (CompactClassificationDiscriminant)	Mahalanobis distance to class means
make (ClassificationDiscriminant)	Construct discriminant analysis classifier from parameters
margin (CompactClassificationDiscriminant)	Classification margins
nLinearCoeffs (CompactClassificationDiscriminant)	Number of nonzero linear coefficients
predict (CompactClassificationDiscriminant)	Predict classification
resubEdge (ClassificationDiscriminant)	Classification edge by resubstitution
resubLoss (ClassificationDiscriminant)	Classification error by resubstitution
resubMargin (ClassificationDiscriminant)	Classification margins by resubstitution
resubPredict (ClassificationDiscriminant)	Predict resubstitution response of classifier
template (ClassificationDiscriminant)	Discriminant analysis classifier template for ensemble

Naive Bayes Classification

fit (NaiveBayes)	Create Naive Bayes classifier object by fitting training data
NaiveBayes	Create NaiveBayes object

posterior (NaiveBayes)

Compute posterior probability of each class for test data

predict (NaiveBayes)

Predict class label for test data

Classification Plots

perfcurve

Compute Receiver Operating Characteristic (ROC) curve or other performance curve for classifier output

view (classregtree)

Plot tree

Nonparametric Supervised Learning

Distance Computation and Classification by Distance

ClassificationKNN	<i>k</i> -nearest neighbor classification
createns	Create object to use in <i>k</i> -nearest neighbors search
crossval (ClassificationKNN)	Cross-validated <i>k</i> -nearest neighbor classifier
edge (ClassificationKNN)	Edge of <i>k</i> -nearest neighbor classifier
fit (ClassificationKNN)	Fit <i>k</i> -nearest neighbor classifier
kfoldEdge (ClassificationPartitionedModel)	Classification edge for observations not used for training
kfoldfun (ClassificationPartitionedModel)	Cross validate function
kfoldLoss (ClassificationPartitionedModel)	Classification loss for observations not used for training
kfoldMargin (ClassificationPartitionedModel)	Classification margins for observations not used for training
kfoldPredict (ClassificationPartitionedModel)	Predict response for observations not used for training
knnsearch	Find <i>k</i> -nearest neighbors using data
knnsearch (ExhaustiveSearcher)	Find <i>k</i> -nearest neighbors using ExhaustiveSearcher object
knnsearch (KDTreeSearcher)	Find <i>k</i> -nearest neighbors using KDTreeSearcher object
loss (ClassificationKNN)	Loss of <i>k</i> -nearest neighbor classifier
margin (ClassificationKNN)	Margin of <i>k</i> -nearest neighbor classifier
pdist	Pairwise distance between pairs of objects

<code>pdist2</code>	Pairwise distance between two sets of observations
<code>predict (ClassificationKNN)</code>	Predict k -nearest neighbor classification
<code>rangesearch</code>	Find all neighbors within specified distance
<code>rangesearch (ExhaustiveSearcher)</code>	Find all neighbors within specified distance using object
<code>rangesearch (KDTreeSearcher)</code>	Find all neighbors within specified distance using object
<code>relieff</code>	Importance of attributes (predictors) using ReliefF algorithm
<code>resubEdge (ClassificationKNN)</code>	Edge of k -nearest neighbor classifier by resubstitution
<code>resubLoss (ClassificationKNN)</code>	Loss of k -nearest neighbor classifier by resubstitution
<code>resubMargin (ClassificationKNN)</code>	Margin of k -nearest neighbor classifier by resubstitution
<code>resubPredict (ClassificationKNN)</code>	Predict resubstitution response of k -nearest neighbor classifier
<code>template (ClassificationKNN)</code>	k -nearest neighbor classifier template for ensemble

Classification Trees

<code>catsplit (classregtree)</code>	Categorical splits used for branches in decision tree
<code>children (classregtree)</code>	Child nodes
<code>classcount (classregtree)</code>	Class counts
<code>ClassificationPartitionedModel</code>	Cross-validated classification model
<code>ClassificationTree</code>	Binary decision tree for classification

<code>classname (classregtree)</code>	Class names for classification decision tree
<code>classprob (classregtree)</code>	Class probabilities
<code>classregtree</code>	Construct classification and regression trees
<code>classregtree</code>	Classification and regression trees
<code>compact (ClassificationTree)</code>	Compact tree
<code>CompactClassificationTree</code>	Compact classification tree
<code>crossval (ClassificationTree)</code>	Cross-validated decision tree
<code>cutcategories (classregtree)</code>	Cut categories
<code>cutpoint (classregtree)</code>	Decision tree cut point values
<code>cuttype (classregtree)</code>	Cut types
<code>cutvar (classregtree)</code>	Cut variable names
<code>cvloss (ClassificationTree)</code>	Classification error by cross validation
<code>edge (CompactClassificationTree)</code>	Classification edge
<code>eval (classregtree)</code>	Predicted responses
<code>fit (ClassificationTree)</code>	Fit classification tree
<code>isbranch (classregtree)</code>	Test node for branch
<code>kfoldEdge (ClassificationPartitionedModel)</code>	Classification edge for observations not used for training
<code>kfoldfun (ClassificationPartitionedModel)</code>	Cross validate function
<code>kfoldLoss (ClassificationPartitionedModel)</code>	Classification loss for observations not used for training
<code>kfoldMargin (ClassificationPartitionedModel)</code>	Classification margins for observations not used for training
<code>kfoldPredict (ClassificationPartitionedModel)</code>	Predict response for observations not used for training
<code>loss (CompactClassificationTree)</code>	Classification error

<code>margin (CompactClassificationTree)</code>	Classification margins
<code>meansurrvarassoc (classregtree)</code>	Mean predictive measure of association for surrogate splits in decision tree
<code>meanSurrVarAssoc (CompactClassificationTree)</code>	Mean predictive measure of association for surrogate splits in decision tree
<code>nodeclass (classregtree)</code>	Class values of nodes of classification tree
<code>nodeerr (classregtree)</code>	Return vector of node errors
<code>nodeprob (classregtree)</code>	Node probabilities
<code>nodesize (classregtree)</code>	Return node size
<code>numnodes (classregtree)</code>	Number of nodes
<code>parent (classregtree)</code>	Parent node
<code>predict (CompactClassificationTree)</code>	Predict classification
<code>predictorImportance (CompactClassificationTree)</code>	Estimates of predictor importance
<code>prune (ClassificationTree)</code>	Produce sequence of subtrees by pruning
<code>prune (classregtree)</code>	Prune tree
<code>prunelist (classregtree)</code>	Pruning levels for decision tree nodes
<code>resubEdge (ClassificationTree)</code>	Classification edge by resubstitution
<code>resubLoss (ClassificationTree)</code>	Classification error by resubstitution
<code>resubMargin (ClassificationTree)</code>	Classification margins by resubstitution
<code>resubPredict (ClassificationTree)</code>	Predict resubstitution response of tree
<code>risk (classregtree)</code>	Node risks
<code>surrutcategories (classregtree)</code>	Categories used for surrogate splits in decision tree

<code>surrctflip (classregtree)</code>	Numeric cutpoint assignments used for surrogate splits in decision tree
<code>surrctpoint (classregtree)</code>	Cutpoints used for surrogate splits in decision tree
<code>surrcttype (classregtree)</code>	Types of surrogate splits used at branches in decision tree
<code>surrctvar (classregtree)</code>	Variables used for surrogate splits in decision tree
<code>surrvarassoc (classregtree)</code>	Predictive measure of association for surrogate splits in decision tree
<code>template (ClassificationTree)</code>	Create classification template
<code>test (classregtree)</code>	Error rate
<code>type (classregtree)</code>	Tree type
<code>varimportance (classregtree)</code>	Compute embedded estimates of input feature importance
<code>view (classregtree)</code>	Plot tree
<code>view (CompactClassificationTree)</code>	View tree

Regression Trees

<code>catsplit (classregtree)</code>	Categorical splits used for branches in decision tree
<code>children (classregtree)</code>	Child nodes
<code>classregtree</code>	Construct classification and regression trees
<code>classregtree</code>	Classification and regression trees
<code>compact (RegressionTree)</code>	Compact regression tree
<code>CompactRegressionTree</code>	Compact regression tree
<code>crossval (RegressionTree)</code>	Cross-validated decision tree
<code>cutcategories (classregtree)</code>	Cut categories

<code>cutpoint (classregtree)</code>	Decision tree cut point values
<code>cuttype (classregtree)</code>	Cut types
<code>cutvar (classregtree)</code>	Cut variable names
<code>cvloss (RegressionTree)</code>	Regression error by cross validation
<code>eval (classregtree)</code>	Predicted responses
<code>fit (RegressionTree)</code>	Binary decision tree for regression
<code>isbranch (classregtree)</code>	Test node for branch
<code>kfoldfun (RegressionPartitionedModel)</code>	Cross validate function
<code>kfoldLoss (RegressionPartitionedModel)</code>	Cross-validation loss of partitioned regression model
<code>kfoldPredict (RegressionPartitionedModel)</code>	Predict response for observations not used for training.
<code>loss (CompactRegressionTree)</code>	Regression error
<code>meansurrvarassoc (classregtree)</code>	Mean predictive measure of association for surrogate splits in decision tree
<code>meanSurrVarAssoc (CompactRegressionTree)</code>	Mean predictive measure of association for surrogate splits in decision tree
<code>nodeerr (classregtree)</code>	Return vector of node errors
<code>nodemean (classregtree)</code>	Mean values of nodes of regression tree
<code>nodeprob (classregtree)</code>	Node probabilities
<code>nodesize (classregtree)</code>	Return node size
<code>numnodes (classregtree)</code>	Number of nodes
<code>parent (classregtree)</code>	Parent node
<code>predict (CompactRegressionTree)</code>	Predict response of regression tree
<code>predictorImportance (CompactRegressionTree)</code>	Estimates of predictor importance

<code>prune (classregtree)</code>	Prune tree
<code>prune (RegressionTree)</code>	Produce sequence of subtrees by pruning
<code>prunelist (classregtree)</code>	Pruning levels for decision tree nodes
<code>RegressionPartitionedModel</code>	Cross-validated regression model
<code>RegressionTree</code>	Regression tree
<code>resubLoss (RegressionTree)</code>	Regression error by resubstitution
<code>resubPredict (RegressionTree)</code>	Predict resubstitution response of tree
<code>risk (classregtree)</code>	Node risks
<code>surrutcategories (classregtree)</code>	Categories used for surrogate splits in decision tree
<code>surrutflip (classregtree)</code>	Numeric cutpoint assignments used for surrogate splits in decision tree
<code>surrutpoint (classregtree)</code>	Cutpoints used for surrogate splits in decision tree
<code>surruttype (classregtree)</code>	Types of surrogate splits used at branches in decision tree
<code>surrutvar (classregtree)</code>	Variables used for surrogate splits in decision tree
<code>surrvarassoc (classregtree)</code>	Predictive measure of association for surrogate splits in decision tree
<code>template (RegressionTree)</code>	Create regression template
<code>test (classregtree)</code>	Error rate
<code>type (classregtree)</code>	Tree type
<code>varimportance (classregtree)</code>	Compute embedded estimates of input feature importance
<code>view (classregtree)</code>	Plot tree
<code>view (CompactRegressionTree)</code>	View tree

Ensemble Methods – Classification

<code>append (TreeBagger)</code>	Append new trees to ensemble
<code>ClassificationBaggedEnsemble</code>	Classification ensemble grown by resampling
<code>ClassificationEnsemble</code>	Ensemble classifier
<code>ClassificationPartitionedEnsemble</code>	Cross-validated classification ensemble
<code>combine (CompactTreeBagger)</code>	Combine two ensembles
<code>compact (ClassificationEnsemble)</code>	Compact classification ensemble
<code>compact (TreeBagger)</code>	Compact ensemble of decision trees
<code>CompactClassificationEnsemble</code>	Compact classification ensemble class
<code>CompactTreeBagger</code>	Compact ensemble of decision trees grown by bootstrap aggregation
<code>crossval (ClassificationEnsemble)</code>	Cross validate ensemble
<code>edge (CompactClassificationEnsemble)</code>	Classification edge
<code>error (CompactTreeBagger)</code>	Error (misclassification probability or MSE)
<code>error (TreeBagger)</code>	Error (misclassification probability or MSE)
<code>fillProximities (TreeBagger)</code>	Proximity matrix for training data
<code>fitensemble</code>	Fitted ensemble for classification or regression
<code>growTrees (TreeBagger)</code>	Train additional trees and add to ensemble
<code>kfoldEdge (ClassificationPartitionedEnsemble)</code>	Classification edge for observations not used for training
<code>kfoldfun (ClassificationPartitionedModel)</code>	Cross validate function

kfoldLoss (ClassificationPartitionedEnsemble)	Classification loss for observations not used for training
kfoldMargin (ClassificationPartitionedModel)	Classification margins for observations not used for training
kfoldPredict (ClassificationPartitionedModel)	Predict response for observations not used for training
loss (CompactClassificationEnsemble)	Classification error
margin (CompactClassificationEnsemble)	Classification margins
margin (CompactTreeBagger)	Classification margin
margin (TreeBagger)	Classification margin
mdsProx (CompactTreeBagger)	Multidimensional scaling of proximity matrix
mdsProx (TreeBagger)	Multidimensional scaling of proximity matrix
meanMargin (CompactTreeBagger)	Mean classification margin
meanMargin (TreeBagger)	Mean classification margin
oobEdge (ClassificationBaggedEnsemble)	Out-of-bag classification edge
oobError (TreeBagger)	Out-of-bag error
oobLoss (ClassificationBaggedEnsemble)	Out-of-bag classification error
oobMargin (ClassificationBaggedEnsemble)	Out-of-bag classification margins
oobMargin (TreeBagger)	Out-of-bag margins
oobMeanMargin (TreeBagger)	Out-of-bag mean margins
oobPredict (ClassificationBaggedEnsemble)	Predict out-of-bag response of ensemble
oobPredict (TreeBagger)	Ensemble predictions for out-of-bag observations

outlierMeasure (CompactTreeBagger)	Outlier measure for data
predict (CompactClassificationEnsemble)	Predict classification
predict (CompactTreeBagger)	Predict response
predict (TreeBagger)	Predict response
predictorImportance (CompactClassificationEnsemble)	Estimates of predictor importance
proximity (CompactTreeBagger)	Proximity matrix for data
removeLearners (CompactClassificationEnsemble)	Remove members of compact classification ensemble
resubEdge (ClassificationEnsemble)	Classification edge by resubstitution
resubLoss (ClassificationEnsemble)	Classification error by resubstitution
resubMargin (ClassificationEnsemble)	Classification margins by resubstitution
resubPredict (ClassificationEnsemble)	Predict ensemble response by resubstitution
resume (ClassificationEnsemble)	Resume training ensemble
resume (ClassificationPartitionedEnsemble)	Resume training learners on cross-validation folds
setDefaultYfit (CompactTreeBagger)	Set default value for predict
TreeBagger	Bootstrap aggregation for ensemble of decision trees

Ensemble Methods – Regression

append (TreeBagger)	Append new trees to ensemble
combine (CompactTreeBagger)	Combine two ensembles
compact (RegressionEnsemble)	Create compact regression ensemble
compact (TreeBagger)	Compact ensemble of decision trees

<code>CompactRegressionEnsemble</code>	Compact regression ensemble class
<code>CompactTreeBagger</code>	Compact ensemble of decision trees grown by bootstrap aggregation
<code>crossval (RegressionEnsemble)</code>	Cross validate ensemble
<code>cvshrink (RegressionEnsemble)</code>	Cross validate shrinking (pruning) ensemble
<code>error (CompactTreeBagger)</code>	Error (misclassification probability or MSE)
<code>error (TreeBagger)</code>	Error (misclassification probability or MSE)
<code>fillProximities (TreeBagger)</code>	Proximity matrix for training data
<code>fitensemble</code>	Fitted ensemble for classification or regression
<code>growTrees (TreeBagger)</code>	Train additional trees and add to ensemble
<code>kfoldfun (RegressionPartitionedModel)</code>	Cross validate function
<code>kfoldLoss (RegressionPartitionedEnsemble)</code>	Cross-validation loss of partitioned regression ensemble
<code>kfoldPredict (RegressionPartitionedModel)</code>	Predict response for observations not used for training.
<code>loss (CompactRegressionEnsemble)</code>	Regression error
<code>mdsProx (CompactTreeBagger)</code>	Multidimensional scaling of proximity matrix
<code>mdsProx (TreeBagger)</code>	Multidimensional scaling of proximity matrix
<code>meanMargin (CompactTreeBagger)</code>	Mean classification margin
<code>oobError (TreeBagger)</code>	Out-of-bag error
<code>oobLoss (RegressionBaggedEnsemble)</code>	Out-of-bag regression error

<code>oobPredict</code> (<code>RegressionBaggedEnsemble</code>)	Predict out-of-bag response of ensemble
<code>oobPredict</code> (<code>TreeBagger</code>)	Ensemble predictions for out-of-bag observations
<code>outlierMeasure</code> (<code>CompactTreeBagger</code>)	Outlier measure for data
<code>predict</code> (<code>CompactRegressionEnsemble</code>)	Predict response of ensemble
<code>predict</code> (<code>CompactTreeBagger</code>)	Predict response
<code>predict</code> (<code>TreeBagger</code>)	Predict response
<code>predictorImportance</code> (<code>CompactRegressionEnsemble</code>)	Estimates of predictor importance
<code>proximity</code> (<code>CompactTreeBagger</code>)	Proximity matrix for data
<code>RegressionBaggedEnsemble</code>	Regression ensemble grown by resampling
<code>RegressionEnsemble</code>	Ensemble regression
<code>RegressionPartitionedEnsemble</code>	Cross-validated regression ensemble
<code>regularize</code> (<code>RegressionEnsemble</code>)	Find weights to minimize resubstitution error plus penalty term
<code>removeLearners</code> (<code>CompactRegressionEnsemble</code>)	Remove members of compact regression ensemble
<code>resubLoss</code> (<code>RegressionEnsemble</code>)	Regression error by resubstitution
<code>resubPredict</code> (<code>RegressionEnsemble</code>)	Predict response of ensemble by resubstitution
<code>resume</code> (<code>RegressionEnsemble</code>)	Resume training ensemble
<code>resume</code> (<code>RegressionPartitionedEnsemble</code>)	Resume training ensemble
<code>setDefaultYfit</code> (<code>CompactTreeBagger</code>)	Set default value for <code>predict</code>

shrink (RegressionEnsemble)

TreeBagger

Prune ensemble

Bootstrap aggregation for ensemble
of decision trees

Hidden Markov Models

<code>hmmdecode</code>	Hidden Markov model posterior state probabilities
<code>hmmestimate</code>	Hidden Markov model parameter estimates from emissions and states
<code>hmmgenerate</code>	Hidden Markov model states and emissions
<code>hmmtrain</code>	Hidden Markov model parameter estimates from emissions
<code>hmmviterbi</code>	Hidden Markov model most probable state path

Design of Experiments

- DOE Plots (p. 18-65)
- Full Factorial Designs (p. 18-65)
- Fractional Factorial Designs (p. 18-66)
- Response Surface Designs (p. 18-66)
- D-Optimal Designs (p. 18-66)
- Latin Hypercube Designs (p. 18-66)
- Quasi-Random Designs (p. 18-67)

DOE Plots

- | | |
|-----------------|--|
| interactionplot | Interaction plot for grouped data |
| maineffectsplot | Main effects plot for grouped data |
| multivarichart | Multivari chart for grouped data |
| rsmdemo | Interactive response surface demonstration |
| rstool | Interactive response surface modeling |

Full Factorial Designs

- | | |
|----------|---------------------------------|
| ff2n | Two-level full factorial design |
| fullfact | Full factorial design |

Fractional Factorial Designs

fracfact	Fractional factorial design
fracfactgen	Fractional factorial design generators

Response Surface Designs

bbdesign	Box-Behnken design
ccdesign	Central composite design

D-Optimal Designs

candexch	<i>D</i> -optimal design from candidate set using row exchanges
candgen	Candidate set generation
cordexch	Coordinate exchange
daugment	<i>D</i> -optimal augmentation
dcovary	<i>D</i> -optimal design with fixed covariates
rowexch	Row exchange
rsmdemo	Interactive response surface demonstration

Latin Hypercube Designs

lhsdesign	Latin hypercube sample
lhsnorm	Latin hypercube sample from normal distribution

Quasi-Random Designs

<code>addlistener (qrandstream)</code>	Add listener for event
<code>delete (qrandstream)</code>	Delete handle object
<code>end (qrandset)</code>	Last index in indexing expression for point set
<code>eq (qrandstream)</code>	Test handle equality
<code>findobj (qrandstream)</code>	Find objects matching specified conditions
<code>findprop (qrandstream)</code>	Find property of MATLAB handle object
<code>ge (qrandstream)</code>	Greater than or equal relation for handles
<code>gt (qrandstream)</code>	Greater than relation for handles
<code>haltonset</code>	Construct Halton quasi-random point set
<code>isvalid (qrandstream)</code>	Test handle validity
<code>le (qrandstream)</code>	Less than or equal relation for handles
<code>length (qrandset)</code>	Length of point set
<code>lt (qrandstream)</code>	Less than relation for handles
<code>ndims (qrandset)</code>	Number of dimensions in matrix
<code>ne (qrandstream)</code>	Not equal relation for handles
<code>net (qrandset)</code>	Generate quasi-random point set
<code>notify (qrandstream)</code>	Notify listeners of event
<code>qrand (qrandstream)</code>	Generate quasi-random points from stream
<code>qrandset</code>	Abstract quasi-random point set class
<code>qrandstream</code>	Construct quasi-random number stream

rand (grandstream)	Generate quasi-random points from stream
reset (grandstream)	Reset state
scramble (grandset)	Scramble quasi-random point set
size (grandset)	Number of dimensions in matrix
sobolset	Construct Sobol quasi-random point set

Statistical Process Control

SPC Plots (p. 18-69)

SPC Functions (p. 18-69)

SPC Plots

capaplot

Process capability plot

controlchart

Shewhart control charts

histfit

Histogram with a distribution fit

normspec

Normal density plot between specifications

SPC Functions

capability

Process capability indices

controlrules

Western Electric and Nelson control rules

gagerr

Gage repeatability and reproducibility study

GUIs

aoctool	Interactive analysis of covariance
dfittool	Interactive distribution fitting
disttool	Interactive density and distribution plots
fsurfht	Interactive contour plot
polytool	Interactive polynomial fitting
randtool	Interactive random number generation
regstats	Regression diagnostics
robustdemo	Interactive robust regression
rsmdemo	Interactive response surface demonstration
rstool	Interactive response surface modeling
surfht	Interactive contour plot

Utilities

combnk	Enumeration of combinations
perms	Enumeration of permutations
statget	Access values in statistics options structure
statset	Create statistics options structure
zscore	Standardized z -scores

Class Reference

- “Data Organization” on page 19-2
- “Probability Distributions” on page 19-3
- “Gaussian Mixture Models” on page 19-5
- “Model Assessment” on page 19-6
- “Parametric Regression” on page 19-7
- “Parametric Classification” on page 19-8
- “Supervised Learning” on page 19-9
- “Quasi-Random Design of Experiments” on page 19-11

Data Organization

In this section...
“Categorical Arrays” on page 19-2
“Dataset Arrays” on page 19-2

Categorical Arrays

categorical	Arrays for categorical data
nominal	Arrays for nominal categorical data
ordinal	Arrays for ordinal categorical data

Dataset Arrays

dataset	Arrays for statistical data
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Probability Distributions

In this section...

“Distribution Objects” on page 19-3

“Quasi-Random Numbers” on page 19-3

“Piecewise Distributions” on page 19-4

Distribution Objects

ProbDist	Object representing probability distribution
ProbDistKernel	Object representing nonparametric probability distribution defined by kernel smoothing
ProbDistParametric	Object representing parametric probability distribution
ProbDistUnivKernel	Object representing univariate kernel probability distribution
ProbDistUnivParam	Object representing univariate parametric probability distribution

Quasi-Random Numbers

haltonset	Halton quasi-random point sets
grandset	Quasi-random point sets
grandstream	Quasi-random number streams
sobolset	Sobol quasi-random point sets

Piecewise Distributions

paretotails

Empirical distributions with Pareto tails

piecewisedistribution

Piecewise-defined distributions

Gaussian Mixture Models

gmdistribution

Gaussian mixture models

Model Assessment

cvpartition

Data partitions for cross validation

Parametric Regression

GeneralizedLinearModel

Generalized linear regression model
class

LinearModel

Linear regression model class

NonLinearModel

Nonlinear regression model class

Parametric Classification

In this section...
“Discriminant Analysis” on page 19-8
“Naive Bayes Classification” on page 19-8

Discriminant Analysis

ClassificationDiscriminant	Discriminant analysis classification
ClassificationPartitionedModel	Cross-validated classification model
CompactClassificationDiscriminant	Compact discriminant analysis class

Naive Bayes Classification

NaiveBayes	Naive Bayes classifier
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Supervised Learning

In this section...

“Distance Classifiers” on page 19-9

“Classification Trees” on page 19-9

“Classification Ensemble Classes” on page 19-9

“Regression Trees” on page 19-10

“Regression Ensemble Classes” on page 19-10

Distance Classifiers

ClassificationKNN	<i>k</i> -nearest neighbor classification
ExhaustiveSearcher	Nearest neighbors search using exhaustive search
KDTreeSearcher	Nearest neighbors search using <i>kd</i> -tree
NeighborSearcher	Nearest neighbor search object

Classification Trees

ClassificationPartitionedModel	Cross-validated classification model
ClassificationTree	Binary decision tree for classification
classregtree	Classification and regression trees
CompactClassificationTree	Compact classification tree

Classification Ensemble Classes

ClassificationBaggedEnsemble	Classification ensemble grown by resampling
ClassificationEnsemble	Ensemble classifier

ClassificationPartitionedEnsemble	Cross-validated classification ensemble
CompactClassificationEnsemble	Compact classification ensemble class
CompactTreeBagger	Compact ensemble of decision trees grown by bootstrap aggregation
TreeBagger	Bootstrap aggregation for ensemble of decision trees

Regression Trees

classregtree	Classification and regression trees
CompactRegressionTree	Compact regression tree
RegressionPartitionedModel	Cross-validated regression model
RegressionTree	Regression tree

Regression Ensemble Classes

CompactRegressionEnsemble	Compact regression ensemble class
CompactTreeBagger	Compact ensemble of decision trees grown by bootstrap aggregation
RegressionBaggedEnsemble	Regression ensemble grown by resampling
RegressionEnsemble	Ensemble regression
RegressionPartitionedEnsemble	Cross-validated regression ensemble
TreeBagger	Bootstrap aggregation for ensemble of decision trees

Quasi-Random Design of Experiments

haltonset

Halton quasi-random point sets

grandset

Quasi-random point sets

grandstream

Quasi-random number streams

sobolset

Sobol quasi-random point sets

Functions — Alphabetical List

addedvarplot

Purpose Added variable plot

Syntax `addedvarplot(X,y,num,inmodel)`
`addedvarplot(X,y,num,inmodel,stats)`

Description `addedvarplot(X,y,num,inmodel)` displays an added variable plot using the predictive terms in X , the response values in y , the added term in column `num` of X , and the model with current terms specified by `inmodel`. X is an n -by- p matrix of n observations of p predictive terms. y is vector of n response values. `num` is a scalar index specifying the column of X with the term to be added. `inmodel` is a logical vector of p elements specifying the columns of X in the current model. By default, all elements of `inmodel` are `false`.

Note `addedvarplot` automatically includes a constant term in all models. Do not enter a column of 1s directly into X .

`addedvarplot(X,y,num,inmodel,stats)` uses the `stats` output from the `stepwisefit` function to improve the efficiency of repeated calls to `addedvarplot`. Otherwise, this syntax is equivalent to the previous syntax.

Added variable plots are used to determine the unique effect of adding a new term to a multilinear model. The plot shows the relationship between the part of the response unexplained by terms already in the model and the part of the new term unexplained by terms already in the model. The “unexplained” parts are measured by the residuals of the respective regressions. A scatter of the residuals from the two regressions forms the added variable plot.

In addition to the scatter of residuals, the plot produced by `addedvarplot` shows 95% confidence intervals on predictions from the fitted line. The fitted line has intercept zero because, under typical linear model assumptions, both of the plotted variables have mean zero. The slope of the fitted line is the coefficient that the new term would have if it were added to the model with terms `inmodel`.

Added variable plots are sometimes known as partial regression leverage plots.

Examples

Load the data in `hald.mat`, which contains observations of the heat of reaction of various cement mixtures:

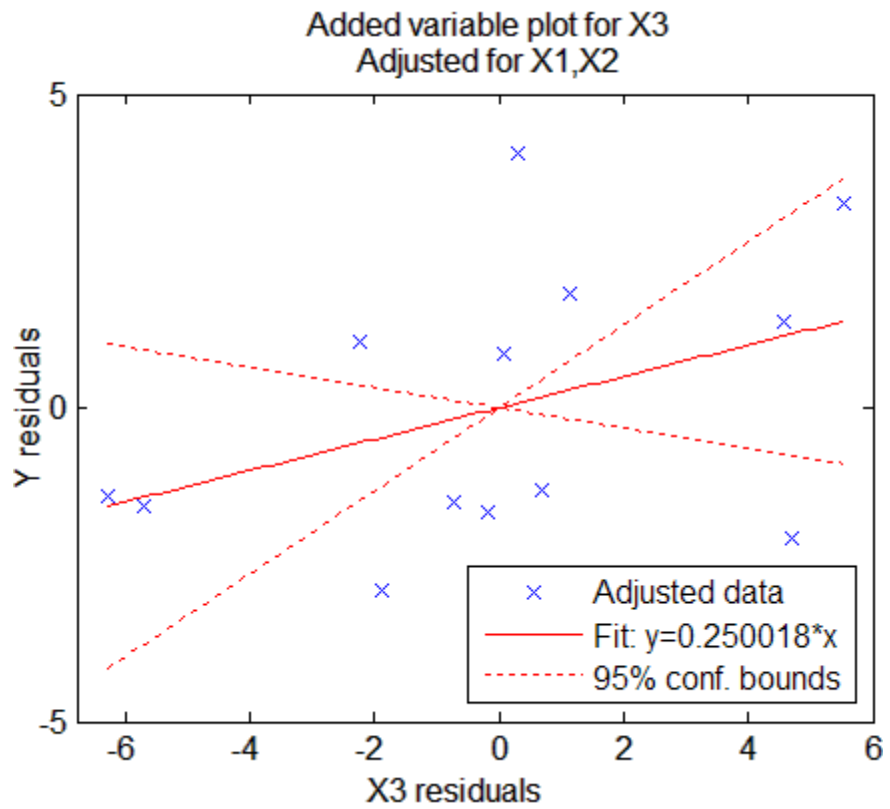
```
load hald
whos
```

Name	Size	Bytes	Class	Attributes
Description	22x58	2552	char	
hald	13x5	520	double	
heat	13x1	104	double	
ingredients	13x4	416	double	

Create an added variable plot to investigate the addition of the third column of `ingredients` to a model consisting of the first two columns:

```
inmodel = [true true false false];
addedvarplot(ingredients,heat,3,inmodel)
```

addedvarplot



The wide scatter and the low slope of the fitted line are evidence against the statistical significance of adding the third column to the model.

See Also

`stepwisefit` | `stepwise`

Purpose Add levels to categorical array

Syntax `B = addlevels(A,newlevels)`

Description `B = addlevels(A,newlevels)` adds new levels to the categorical array `A`. `newlevels` is a cell array of strings or a 2-D character matrix that specifies the levels to add. `addlevels` adds the new levels at the end of the list of possible categorical levels in `A`, but does not modify the value of any element. `B` does not contain elements at the new levels.

Examples **Example 1**

Add levels for additional species in Fisher's iris data:

```
load fisheriris
species = nominal(species,...
                  {'Species1','Species2','Species3'},...
                  {'setosa','versicolor','virginica'});
species = addlevels(species,{'Species4','Species5'});
getlabels(species)
ans =
    'Species1' 'Species2' 'Species3' 'Species4' 'Species5'
```

Example 2

- 1 Load patient data from the CSV file `hospital.dat` and store the information in a dataset array with observation names given by the first column in the data (patient identification):

```
patients = dataset('file','hospital.dat',...
                  'delimiter',';',...
                  'ReadObsNames',true);
```

- 2 Make the `{0,1}`-valued variable `smoke` nominal, and change the labels to 'No' and 'Yes':

```
patients.smoke = nominal(patients.smoke,{'No','Yes'});
```

categorical.addlevels

- 3** Add new levels to `smoke` as placeholders for more detailed histories of smokers:

```
patients.smoke = addlevels(patients.smoke,...  
                           {'0-5 Years', '5-10 Years', 'LongTerm'});
```

- 4** Assuming the nonsmokers have never smoked, relabel the 'No' level:

```
patients.smoke = setlabels(patients.smoke, 'Never', 'No');
```

- 5** Drop the undifferentiated 'Yes' level from `smoke`:

```
patients.smoke = droplevels(patients.smoke, 'Yes');
```

Warning: `OLDLEVELS` contains categorical levels that were present in `A`, caused some array elements to have undefined levels.

Note that smokers now have an undefined level.

- 6** Set each smoker to one of the new levels, by observation name:

```
patients.smoke('YPL-320') = '5-10 Years';
```

See Also

`droplevels` | `getlabels` | `islevel` | `mergelevels` | `reorderlevels`

Purpose

Add listener for event

Syntax

```
e1 = addlistener(hsource, 'eventname', callback)
e1 = addlistener(hsource, property, 'eventname', callback)
```

Description

`e1 = addlistener(hsource, 'eventname', callback)` creates a listener for the event named `eventname`, the source of which is handle object `hsource`. If `hsource` is an array of source handles, the listener responds to the named event on any handle in the array. `callback` is a function handle that is invoked when the event is triggered.

`e1 = addlistener(hsource, property, 'eventname', callback)` adds a listener for a property event. `eventname` must be one of the strings `'PreGet'`, `'PostGet'`, `'PreSet'`, and `'PostSet'`. `property` must be either a property name or cell array of property names, or a `meta.property` or array of `meta.property`. The properties must belong to the class of `hsource`. If `hsource` is scalar, `property` can include dynamic properties.

For all forms, `addlistener` returns an `event.listener`. To remove a listener, delete the object returned by `addlistener`. For example, `delete(e1)` calls the handle class `delete` method to remove the listener and delete it from the workspace.

See Also

`delete` | `dynamicprops` | `event.listener` | `events` | `meta.property`
| `notify` | `grandstream` | `reset`

GeneralizedLinearModel.addTerms

Purpose	Add terms to generalized linear model
Syntax	<code>mdl1 = addTerms(mdl, terms)</code>
Description	<code>mdl1 = addTerms(mdl, terms)</code> returns a generalized linear model the same as <code>mdl</code> but with additional terms.
Input Arguments	<p>mdl</p> <p>Generalized linear model, as constructed by <code>GeneralizedLinearModel.fit</code> or <code>GeneralizedLinearModel.stepwise</code>.</p> <p>terms</p> <p>Terms to add to the <code>mdl</code> regression model. Specify as either a:</p> <ul style="list-style-type: none">• Text string representing one or more terms to add. For details, see “Wilkinson Notation” on page 20-9.• Row or rows in the terms matrix (see <code>modelspec</code> in <code>LinearModel.fit</code>). For example, if there are three variables A, B, and C: <code>[0 0 0]</code> represents a constant term or intercept <code>[0 1 0]</code> represents B; equivalently, $A^0 * B^1 * C^0$ <code>[1 0 1]</code> represents $A * C$ <code>[2 0 0]</code> represents A^2 <code>[0 1 2]</code> represents $B * (C^2)$
Output Arguments	<p>mdl1</p> <p>Generalized linear model, the same as <code>mdl</code> but with additional terms given in <code>terms</code>. You can set <code>mdl1</code> equal to <code>mdl</code> to overwrite <code>mdl</code>.</p>

Definitions

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k , where k is a positive integer	A, A^2, \dots, A^k
$A+B$	A, B
$A*B$	$A, B, A*B$
$A:B$	$A*B$ only
$-B$	Do not include B
$A*B+C$	$A, B, C, A*B$
$A+B+C+A:B$	$A, B, C, A*B$
$A*B*C - A:B:C$	$A, B, C, A*B, A*C, B*C$
$A*(B + C)$	$A, B, C, A*B, A*C$

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using `-1`.

For details, see Wilkinson and Rogers [1].

Examples

Add a term to a generalized linear regression model

Create a model using just one predictor, then add a second.

Generate artificial data for the model, Poisson random numbers with two underlying predictors $X(1)$ and $X(2)$.

```
rng('default') % for reproducibility
rndvars = randn(100,2);
X = [2+rndvars(:,1),rndvars(:,2)];
mu = exp(1 + X*[1;2]);
```

GeneralizedLinearModel.addTerms

```
y = poissrnd(mu);
```

Create a generalized linear regression model of Poisson data. Use just the first predictor in the model.

```
mdl = GeneralizedLinearModel.fit(X,y,...  
    'y ~ x1','distr','poisson')
```

```
mdl =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x1  
Distribution = Poisson
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	2.7784	0.014043	197.85	0
x1	1.1732	0.0033653	348.6	0

100 observations, 98 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 1.25e+05, p-value = 0

Add the second predictor to the model.

```
mdl1 = addTerms(mdl,'x2')
```

```
mdl1 =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x1 + x2  
Distribution = Poisson
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	1.0405	0.022122	47.034	0
x1	0.9968	0.003362	296.49	0
x2	1.987	0.0063433	313.24	0

```
100 observations, 97 error degrees of freedom
Dispersion: 1
Chi^2-statistic vs. constant model: 2.95e+05, p-value = 0
```

References

[1] Wilkinson, G. N., and C. E. Rogers. *Symbolic description of factorial models for analysis of variance*. J. Royal Statistics Society 22, pp. 392–399, 1973.

Alternatives

step adds or removes terms from a model using a greedy one-step algorithm.

See Also

GeneralizedLinearModel | removeTerms | step |
GeneralizedLinearModel.stepwise |

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.addTerms

Purpose Add terms to linear regression model

Syntax `mdl1 = addTerms(mdl, terms)`

Description `mdl1 = addTerms(mdl, terms)` returns a linear model the same as `mdl` but with additional terms.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

terms

Terms to add to the `mdl` regression model. Specify as either a:

- Text string representing one or more terms to add. For details, see “Wilkinson Notation” on page 20-12.
- Row or rows in the terms matrix (see `modelspec` in `LinearModel.fit`). For example, if there are three variables A, B, and C:

```
[0 0 0] represents a constant term or intercept  
[0 1 0] represents B; equivalently, A^0 * B^1 * C^0  
[1 0 1] represents A*C  
[2 0 0] represents A^2  
[0 1 2] represents B*(C^2)
```

Output Arguments

mdl1

Linear model, the same as `mdl` but with additional terms given in `terms`. You can set `mdl1` equal to `mdl` to overwrite `mdl`.

Definitions

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k , where k is a positive integer	A, A^2, \dots, A^k
$A+B$	A, B
$A*B$	$A, B, A*B$
$A:B$	$A*B$ only
$-B$	Do not include B
$A*B+C$	$A, B, C, A*B$
$A+B+C+A:B$	$A, B, C, A*B$
$A*B*C - A:B:C$	$A, B, C, A*B, A*C, B*C$
$A*(B + C)$	$A, B, C, A*B, A*C$

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using `-1`.

For details, see Wilkinson and Rogers [1].

Examples

Add a Term to a Model

Create a model of the `carsmall` data without any interactions, then add an interaction term.

Load the `carsmall` data and make a model of the MPG as a function of weight and model year.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Add an interaction term to `mdl`.

```
terms = 'Year*Weight';
mdl1 = addTerms(mdl,terms)
```

LinearModel.addTerms

```
mdl1 =
```

```
Linear regression model:
```

```
MPG ~ 1 + Weight*Year + Weight^2
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	48.045	6.779	7.0874	3.3967e-10
Weight	-0.012624	0.0041455	-3.0454	0.0030751
Year_76	2.7768	3.0538	0.90931	0.3657
Year_82	16.416	4.9802	3.2962	0.0014196
Weight:Year_76	-0.00020693	0.00092403	-0.22394	0.82333
Weight:Year_82	-0.0032574	0.0018919	-1.7217	0.088673
Weight^2	1.0121e-06	6.12e-07	1.6538	0.10177

```
Number of observations: 94, Error degrees of freedom: 87
```

```
Root Mean Squared Error: 2.76
```

```
R-squared: 0.89, Adjusted R-Squared 0.882
```

```
F-statistic vs. constant model: 117, p-value = 1.88e-39
```

References

[1] Wilkinson, G. N., and C. E. Rogers. *Symbolic description of factorial models for analysis of variance*. J. Royal Statistics Society 22, pp. 392–399, 1973.

Alternatives

Use `LinearModel.stepwise` to select a model from a starting model, continuing until no single step is beneficial.

Use `removeTerms` to remove particular terms.

Use `step` to optimally improve the model by adding or removing terms.

See Also

`LinearModel` | `removeTerms` | `step` | `LinearModel.stepwise`

How To

- “Linear Regression” on page 9-7

Purpose Akaike Information Criterion

Description The Akaike Information Criterion: $2 \cdot N \log L + 2 \cdot m$, where m is the number of estimated parameters.

Note This property applies only to gmdistribution objects constructed with `fit`.

andrewsplot

Purpose Andrews plot

Syntax

```
andrewsplot(X)
andrewsplot(X, ..., 'Standardize', standopt)
andrewsplot(X, ..., 'Quantile', alpha)
andrewsplot(X, ..., 'Group', group)
andrewsplot(X, ..., 'PropName', PropVal, ...)
h = andrewsplot(X, ...)
```

Description `andrewsplot(X)` creates an Andrews plot of the multivariate data in the matrix `X`. The rows of `X` correspond to observations, the columns to variables. Andrews plots represent each observation by a function $f(t)$ of a continuous dummy variable t over the interval $[0,1]$. $f(t)$ is defined for the i th observation in `X` as

$$f(t) = X(i,1) / \sqrt{2} + X(i,2)\sin(2\pi t) + X(i,3)\cos(2\pi t) + \dots$$

`andrewsplot` treats NaN values in `X` as missing values and ignores the corresponding rows.

`andrewsplot(X, ..., 'Standardize', standopt)` creates an Andrews plot where *standopt* is one of the following:

- 'on' — scales each column of `X` to have mean 0 and standard deviation 1 before making the plot.
- 'PCA' — creates an Andrews plot from the principal component scores of `X`, in order of decreasing eigenvalue. (See `pca`.)
- 'PCAStd' — creates an Andrews plot using the standardized principal component scores. (See `pca`.)

`andrewsplot(X, ..., 'Quantile', alpha)` plots only the median and the α and $(1 - \alpha)$ quantiles of $f(t)$ at each value of t . This is useful if `X` contains many observations.

`andrewsplot(X, ..., 'Group', group)` plots the data in different groups with different colors. Groups are defined by `group`, a numeric array containing a group index for each observation. `group` can also be a

categorical array, character matrix, or cell array of strings containing a group name for each observation.

`andrewsplot(X,...,'PropName',PropVal,...)` sets optional lineseries object properties to the specified values for all lineseries objects created by `andrewsplot`. (See `lineseriesproperties`.)

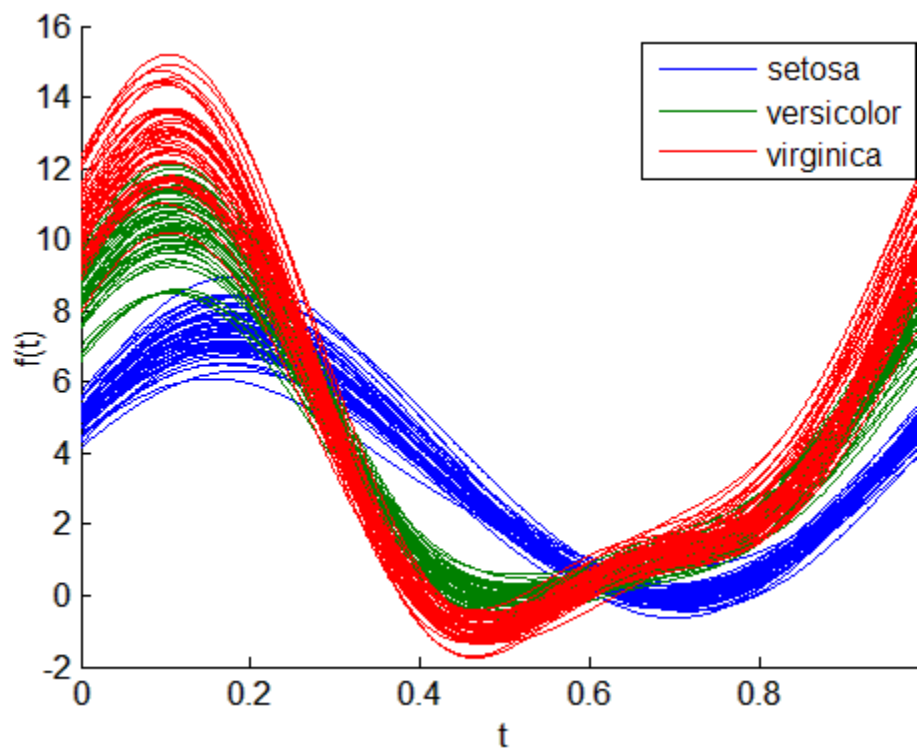
`h = andrewsplot(X,...)` returns a column vector of handles to the lineseries objects created by `andrewsplot`, one handle per row of `X`. If you use the `'Quantile'` input parameter, `h` contains one handle for each of the three lineseries objects created. If you use both the `'Quantile'` and the `'Group'` input parameters, `h` contains three handles for each group.

Examples

Make a grouped plot of the Fisher iris data:

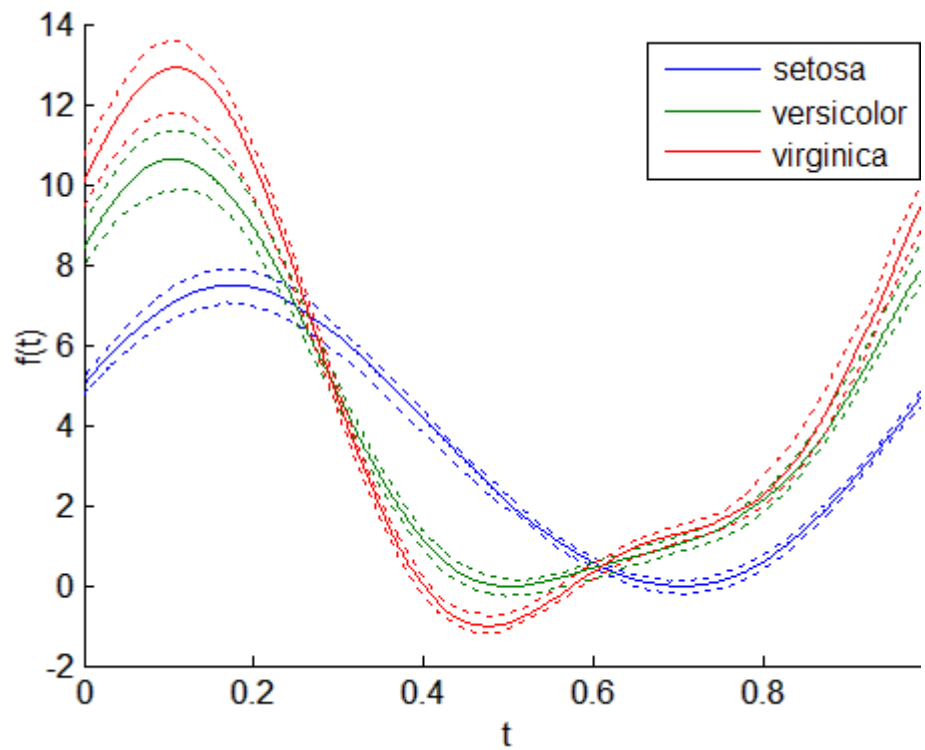
```
load fisheriris
andrewsplot(meas,'group',species)
```

andrewsplot



Plot only the median and quartiles of each group:

```
andrewsplot(meas, 'group', species, 'quantile', .25)
```



See Also

[parallelcoords](#) | [glyphplot](#)

How To

- “Grouping Variables” on page 2-72

LinearModel.anova

Purpose Analysis of variance for linear model

Syntax

```
tbl = anova mdl
tbl = anova mdl, anovatype
tbl = anova mdl, anovatype, sstype
```

Description

tbl = anova(mdl) returns a dataset array with summary ANOVA statistics.

tbl = anova(mdl, anovatype) returns ANOVA statistics of the chosen type.

tbl = anova(mdl, anovatype, sstype) computes ANOVA statistics using the chosen type of sum of squares.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

anovatype

ANOVA type:

- 'component' — tbl displays a 'components' ANOVA table, with sums of squares and F tests attributable to each term in the model except the constant term.
- 'summary' — tbl displays a summary ANOVA table with an F test for the model as a whole.
 - If there are both linear and higher-order terms, there is also an F test for the higher-order terms as a group.
 - If there are replications (multiple observations sharing the same predictor values), there is also an F test for lack-of-fit computed by decomposing the residual sum of squares into a sum of squares for the replicated observations and the remaining sum of squares.

Default: 'component'

sstype

When anovatype is 'component', choose the sum of squares type:

- 1
- 2
- 3
- 'h'

For details, see “Sum of Squares” on page 20-37.

Default: 'h'

Output Arguments

tbl

Dataset array containing summary ANOVA statistics. `tbl` depends on `anovatype`:

- 'component':
 - Sum of squares
 - Degrees of freedom
 - Mean squares
 - F statistic
 - p -value
 - Formula used for model
- 'summary':
 - Total Sum of Squares
 - Model Sum of Squares

LinearModel.anova

- Linear Sum of Squares (present if model has powers or interactions)
- Nonlinear Sum of Squares (present if model has powers or interactions)
- Residual Sum of Squares
 - Lack-of-fit Sum of Squares (present if model has replicates)
 - Pure error Sum of Squares (present if model has replicates)

Examples

Component ANOVA Table

Create a component ANOVA table from a model of the `carsmall` data.

Load the `carsmall` data and make a model of the MPG as a function of weight and model year.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Create an ANOVA table.

```
tbl = anova(mdl)
```

```
tbl =
```

	SumSq	DF	MeanSq	F	pValue
Weight	2050.2	1	2050.2	265.11	1.9885e-28
Year	849.55	2	424.77	54.927	2.9042e-16
Weight^2	76.688	1	76.688	9.9164	0.0022303
Error	688.27	89	7.7334		

Summary ANOVA Table

Create a summary ANOVA table from a model of the `carsmall` data.

Load the `carsmall` data and make a model of the MPG as a function of weight and model year.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Create a summary ANOVA table.

```
tbl = anova(mdl,'summary')
```

```
tbl =
```

	SumSq	DF	MeanSq	F	pValue
Total	6005.3	93	64.573		
Model	5317	4	1329.3	171.88	5.5208e-41
. Linear	5240.3	3	1746.8	225.87	1.7302e-41
. Nonlinear	76.688	1	76.688	9.9164	0.0022303
Residual	688.27	89	7.7334		
. Lack of fit	663.77	86	7.7183	0.9451	0.62874
. Pure error	24.5	3	8.1667		

The summary ANOVA table shows tests for groups of terms. The nonlinear group consists of just the Weight^2 term, so it has the same p -value as that term in “Component ANOVA Table” on page 20-22. The F statistic comparing the residual sum of squares to a “pure error” estimate from replicated observations shows no evidence of lack of fit.

Alternatives

More complete ANOVA statistics are available in the `anova1`, `anova2`, and `anovan` functions.

See Also

`LinearModel`

Tutorials

- “ANOVA” on page 9-19

How To

- “Linear Regression” on page 9-7

anova1

Purpose One-way analysis of variance

Syntax

```
p = anova1(X)
p = anova1(X,group)
p = anova1(X,group,displayopt)
[p,table] = anova1(...)
[p,table,stats] = anova1(...)
```

Description `p = anova1(X)` performs balanced one-way ANOVA for comparing the means of two or more columns of data in the matrix `X`, where each column represents an independent sample containing mutually independent observations. The function returns the p -value under the null hypothesis that all samples in `X` are drawn from populations with the same mean.

If `p` is near zero, it casts doubt on the null hypothesis and suggests that at least one sample mean is significantly different than the other sample means. Common significance levels are 0.05 or 0.01.

The `anova1` function displays two figures, the standard ANOVA table and a box plot of the columns of `X`.

The standard ANOVA table divides the variability of the data into two parts:

- Variability due to the differences among the column means (variability *between* groups)
- Variability due to the differences between the data in each column and the column mean (variability *within* groups)

The standard ANOVA table has six columns:

- 1 The source of the variability.
- 2 The sum of squares (SS) due to each source.
- 3 The degrees of freedom (df) associated with each source.
- 4 The mean squares (MS) for each source, which is the ratio SS/df .

5 The F -statistic, which is the ratio of the mean squares.

6 The p -value, which is derived from the cdf of F .

The box plot of the columns of X suggests the size of the F -statistic and the p -value. Large differences in the center lines of the boxes correspond to large values of F and correspondingly small values of p .

anova1 treats NaN values as missing, and disregards them.

`p = anova1(X,group)` performs ANOVA by group. For more information on grouping variables, see “Grouping Variables” on page 2-72.

If X is a matrix, anova1 treats each column as a separate group, and evaluates whether the population means of the columns are equal. This form of anova1 is appropriate when each group has the same number of elements (balanced ANOVA). `group` can be a character array or a cell array of strings, with one row per column of X , containing group names. Enter an empty array (`[]`) or omit this argument if you do not want to specify group names.

If X is a vector, `group` must be a categorical variable, vector, string array, or cell array of strings with one name for each element of X . X values corresponding to the same value of `group` are placed in the same group. This form of anova1 is appropriate when groups have different numbers of elements (unbalanced ANOVA).

If `group` contains empty or NaN-valued cells or strings, the corresponding observations in X are disregarded.

`p = anova1(X,group,displayopt)` enables the ANOVA table and box plot displays when `displayopt` is 'on' (default) and suppresses the displays when `displayopt` is 'off'. Notches in the boxplot provide a test of group medians (see `boxplot`) different from the F test for means in the ANOVA table.

`[p,table] = anova1(...)` returns the ANOVA table (including column and row labels) in the cell array `table`. Copy a text version of the ANOVA table to the clipboard using the Copy Text item on the **Edit** menu.

`[p,table,stats] = anova1(...)` returns a structure `stats` used to perform a follow-up multiple comparison test. `anova1` evaluates the hypothesis that the samples all have the same mean against the alternative that the means are not all the same. Sometimes it is preferable to perform a test to determine which pairs of means are significantly different, and which are not. Use the `multcompare` function to perform such tests by supplying the `stats` structure as input.

Assumptions

The ANOVA test makes the following assumptions about the data in `X`:

- All sample populations are normally distributed.
- All sample populations have equal variance.
- All observations are mutually independent.

The ANOVA test is known to be robust with respect to modest violations of the first two assumptions.

Examples

Example 1

Create `X` with columns that are constants plus random normal disturbances with mean zero and standard deviation one:

```
X = meshgrid(1:5)
```

```
X =  
  1  2  3  4  5  
  1  2  3  4  5  
  1  2  3  4  5  
  1  2  3  4  5  
  1  2  3  4  5
```

```
X = X + normrnd(0,1,5,5)
```

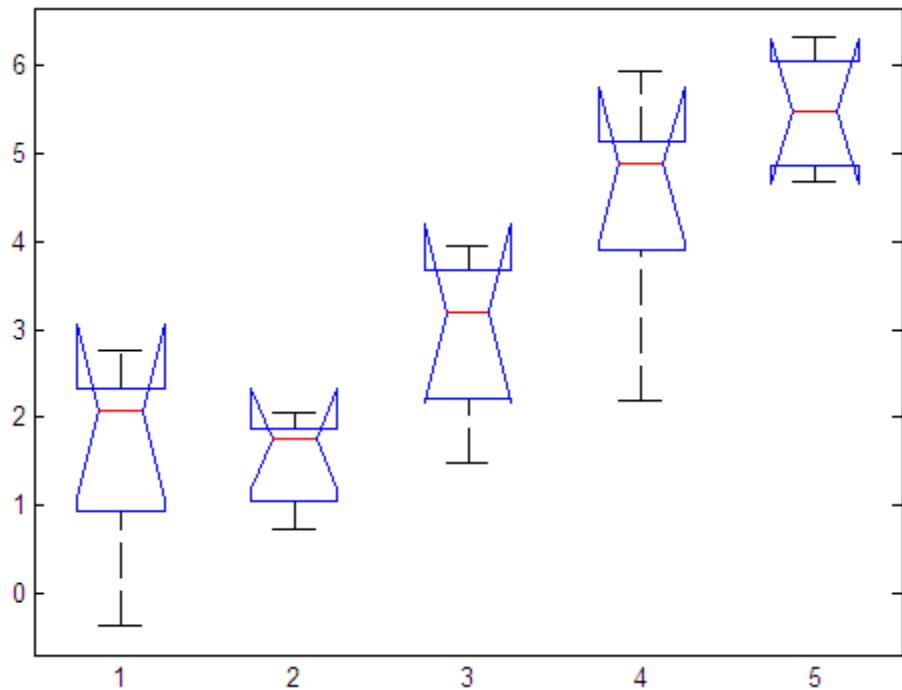
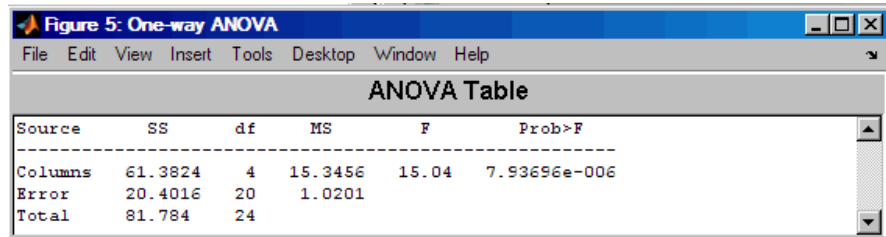
```
X =  
  1.3550    2.0662    2.4688    5.9447    5.4897  
  2.0693    1.7611    1.4864    4.8826    6.3222  
  2.1919    0.7276    3.1905    4.8768    4.6841  
  2.7620    1.8179    3.9506    4.4678    4.9291  
 -0.3626    1.1685    3.5742    2.1945    5.9465
```

Perform one-way ANOVA:

```
p = anova1(X)
```

```
p =
```

```
7.9370e-006
```



The very small p value indicates that differences between column means are highly significant. The probability of this outcome under the null hypothesis (that samples drawn from the same population would have means differing by the amounts seen in X) is equal to the p -value.

Example 2

The following example is from a study of the strength of structural beams in Hogg. The vector `strength` measures deflections of beams in thousandths of an inch under 3,000 pounds of force. The vector `alloy` identifies each beam as steel ('st'), alloy 1 ('a11'), or alloy 2 ('a12'). (Although alloy is sorted in this example, grouping variables do not need to be sorted.) The null hypothesis is that steel beams are equal in strength to beams made of the two more expensive alloys.

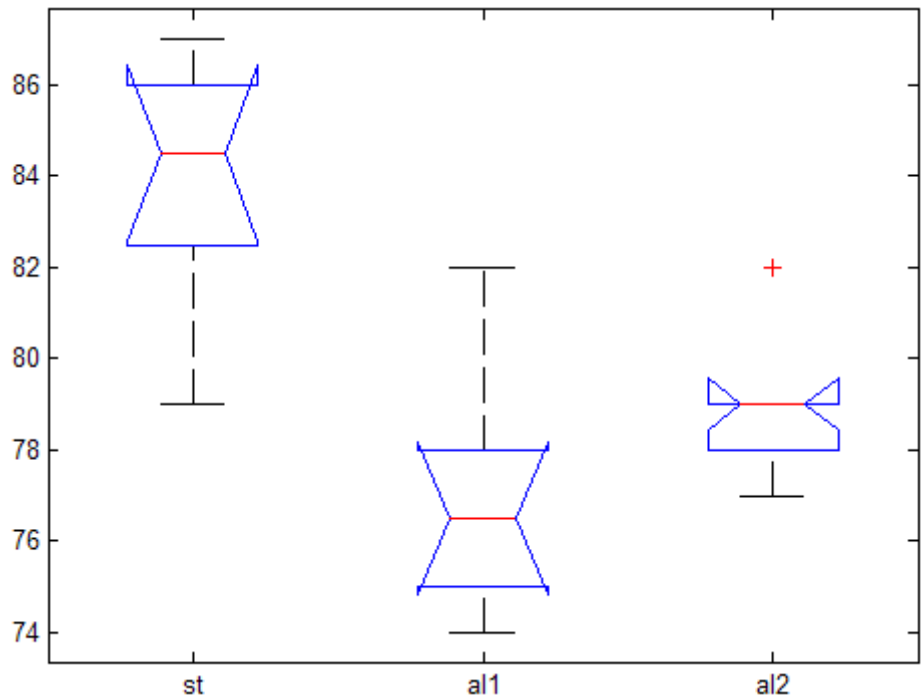
```
strength = [82 86 79 83 84 85 86 87 74 82 ...  
           78 75 76 77 79 79 77 78 82 79];
```

```
alloy = {'st','st','st','st','st','st','st','st',...  
        'a11','a11','a11','a11','a11','a11',...  
        'a12','a12','a12','a12','a12','a12'};
```

```
p = anova1(strength,alloy)
```

```
p =  
1.5264e-004
```

Source	SS	df	MS	F	Prob>F
Columns	184.8	2	92.4	15.4	0.0002
Error	102	17	6		
Total	286.8	19			



The p -value suggests rejection of the null hypothesis. The box plot shows that steel beams deflect more than beams made of the more expensive alloys.

References

[1] Hogg, R. V., and J. Ledolter. *Engineering Statistics*. New York: MacMillan, 1987.

See Also

anova2 | anovan | boxplot | manova1 | multcompare

How To

- “Grouping Variables” on page 2-72

Purpose Two-way analysis of variance

Syntax

```
p = anova2(X, reps)
p = anova2(X, reps, displayopt)
[p, table] = anova2(...)
[p, table, stats] = anova2(...)
```

Description `p = anova2(X, reps)` performs a balanced two-way ANOVA for comparing the means of two or more columns and two or more rows of the observations in X . The data in different columns represent changes in factor A . The data in different rows represent changes in factor B . If there is more than one observation for each combination of factors, input `reps` indicates the number of replicates in each position, which must be constant. (For unbalanced designs, use `anovan`.)

The matrix below shows the format for a set-up where column factor A has two levels, row factor B has three levels, and there are two replications (`reps` = 2). The subscripts indicate row, column, and replicate, respectively.

$$\begin{array}{cc} A = 1 & A = 2 \\ \left[\begin{array}{cc} x_{111} & x_{121} \\ x_{112} & x_{122} \\ x_{211} & x_{221} \\ x_{212} & x_{222} \\ x_{311} & x_{321} \\ x_{312} & x_{322} \end{array} \right] & \left. \begin{array}{l} \} B = 1 \\ \} B = 2 \\ \} B = 3 \end{array} \right\} \end{array}$$

When `reps` is 1 (default), `anova2` returns two p -values in vector `p`:

- 1 The p value for the null hypothesis, H_{0A} , that all samples from factor A (i.e., all column-samples in X) are drawn from the same population
- 2 The p value for the null hypothesis, H_{0B} , that all samples from factor B (i.e., all row-samples in X) are drawn from the same population

When `reps` is greater than 1, `anova2` returns a third p value in vector `p`:

- 3 The p value for the null hypothesis, H_{0AB} , that the effects due to factors A and B are *additive* (i.e., that there is no interaction between factors A and B)

If any p value is near zero, this casts doubt on the associated null hypothesis. A sufficiently small p value for H_{0A} suggests that at least one column-sample mean is significantly different than the other column-sample means; i.e., there is a main effect due to factor A. A sufficiently small p value for H_{0B} suggests that at least one row-sample mean is significantly different than the other row-sample means; i.e., there is a main effect due to factor B. A sufficiently small p value for H_{0AB} suggests that there is an interaction between factors A and B. The choice of a limit for the p value to determine whether a result is “statistically significant” is left to the researcher. It is common to declare a result significant if the p value is less than 0.05 or 0.01.

`anova2` also displays a figure showing the standard ANOVA table, which divides the variability of the data in `X` into three or four parts depending on the value of `reps`:

- The variability due to the differences among the column means
- The variability due to the differences among the row means
- The variability due to the interaction between rows and columns (if `reps` is greater than its default value of one)
- The remaining variability not explained by any systematic source

The ANOVA table has five columns:

- The first shows the source of the variability.
- The second shows the Sum of Squares (SS) due to each source.
- The third shows the degrees of freedom (df) associated with each source.
- The fourth shows the Mean Squares (MS), which is the ratio SS/df.

- The fifth shows the F statistics, which is the ratio of the mean squares.

`p = anova2(X, reps, displayopt)` enables the ANOVA table display when `displayopt` is 'on' (default) and suppresses the display when `displayopt` is 'off'.

`[p, table] = anova2(...)` returns the ANOVA table (including column and row labels) in cell array `table`. (Copy a text version of the ANOVA table to the clipboard by using the Copy Text item on the **Edit** menu.)

`[p, table, stats] = anova2(...)` returns a `stats` structure that you can use to perform a follow-up multiple comparison test.

The `anova2` test evaluates the hypothesis that the row, column, and interaction effects are all the same, against the alternative that they are not all the same. Sometimes it is preferable to perform a test to determine *which pairs* of effects are significantly different, and which are not. Use the `multcompare` function to perform such tests by supplying the `stats` structure as input.

Examples

The data below come from a study of popcorn brands and popper type (Hogg 1987). The columns of the matrix `popcorn` are brands (Gourmet, National, and Generic). The rows are popper type (Oil and Air.) The study popped a batch of each brand three times with each popper. The values are the yield in cups of popped popcorn.

```
load popcorn

popcorn
popcorn =
    5.5000    4.5000    3.5000
    5.5000    4.5000    4.0000
    6.0000    4.0000    3.0000
    6.5000    5.0000    4.0000
    7.0000    5.5000    5.0000
    7.0000    5.0000    4.5000
```

```
p = anova2(popcorn,3)
p =
    0.0000    0.0001    0.7462
```

Source	SS	df	MS	F	Prob>F
Columns	15.75	2	7.875	56.7	0
Rows	4.5	1	4.5	32.4	0.0001
Interaction	0.0833	2	0.04167	0.3	0.7462
Error	1.6667	12	0.13889		
Total	22	17			

The vector `p` shows the p -values for the three brands of popcorn, 0.0000, the two popper types, 0.0001, and the interaction between brand and popper type, 0.7462. These values indicate that both popcorn brand and popper type affect the yield of popcorn, but there is no evidence of a synergistic (interaction) effect of the two.

The conclusion is that you can get the greatest yield using the Gourmet brand and an Air popper (the three values `popcorn(4:6,1)`).

References

[1] Hogg, R. V., and J. Ledolter. *Engineering Statistics*. New York: MacMillan, 1987.

See Also

`anova1` | `anovan`

Purpose *N*-way analysis of variance

Syntax

```
p = anovan(y,group)
p = anovan(y,group,param,val)
[p,table] = anovan(y,group,param,val)
[p,table,stats] = anovan(y,group,param,val)
[p,table,stats,terms] = anovan(y,group,param,val)
```

Description `p = anovan(y,group)` performs multiway (*n*-way) analysis of variance (ANOVA) for testing the effects of multiple factors on the mean of the vector *y*. This test compares the variance explained by factors to the left over variance that cannot be explained. The factors and factor levels of the observations in *y* are assigned by the cell array `group`. Each of the cells in the cell array `group` contains a list of factor levels identifying the observations in *y* with respect to one of the factors. The list within each cell can be a categorical array, numeric vector, character matrix, or single-column cell array of strings, and must have the same number of elements as *y*. The fitted ANOVA model includes the main effects of each grouping variable. All grouping variables are treated as fixed effects by default. The result `p` is a vector of *p*-values, one per term. For an example, see “Example of Three-Way ANOVA” on page 20-38.

`p = anovan(y,group,param,val)` specifies one or more of the parameter name/value pairs described in the following table.

Parameter	Value
'alpha'	A number between 0 and 1 requesting 100(1 – <i>alpha</i>)% confidence bounds (default 0.05 for 95% confidence)
'continuous'	A vector of indices indicating which grouping variables should be treated as continuous predictors rather than as categorical predictors.
'display'	'on' displays an ANOVA table (the default) 'off' omits the display

Parameter	Value
'model'	The type of model used. See “Model Type” on page 20-36 for a description of this parameter.
'nested'	A matrix M of 0's and 1's specifying the nesting relationships among the grouping variables. M(i,j) is 1 if variable i is nested in variable j.
'random'	A vector of indices indicating which grouping variables are random effects (all are fixed by default). See “ANOVA with Random Effects” on page 8-19 for an example of how to use 'random'.
'sstype'	1, 2, 3 (default), or h specifies the type of sum of squares. See “Sum of Squares” on page 20-37 for a description of this parameter.
'varnames'	A character matrix or a cell array of strings specifying names of grouping variables, one per grouping variable. When you do not specify 'varnames', the default labels 'X1', 'X2', 'X3', ..., 'XN' are used. See “ANOVA with Random Effects” on page 8-19 for an example of how to use 'varnames'.

`[p,table] = anovan(y,group,param,val)` returns the ANOVA table (including factor labels) in cell array `table`. (Copy a text version of the ANOVA table to the clipboard by using the Copy Text item on the **Edit** menu.)

`[p,table,stats] = anovan(y,group,param,val)` returns a `stats` structure that you can use to perform a follow-up multiple comparison test with the `multcompare` function. See “The Stats Structure” on page 20-41The Stats Structure for more information.

`[p,table,stats,terms] = anovan(y,group,param,val)` returns the main and interaction terms used in the ANOVA computations. The terms are encoded in the output matrix `terms` using the same format described above for input 'model'. When you specify 'model' itself in this matrix format, the matrix returned in `terms` is identical.

Model Type

This section explains how to use the argument 'model' with the syntax:

```
[...] = anovan(y,group,'model',modeltype)
```

The argument *modeltype*, which specifies the type of model the function uses, can be any one of the following:

- 'linear' — The default 'linear' model computes only the p -values for the null hypotheses on the N main effects.
- 'interaction' — The 'interaction' model computes the p -values

for null hypotheses on the N main effects and the $\binom{N}{2}$ two-factor interactions.

- 'full' — The 'full' model computes the p -values for null hypotheses on the N main effects and interactions at all levels.
- An integer — For an integer value of *modeltype*, k ($k \leq N$), *anovan* computes all interaction levels through the k th level. For example, the value 3 means main effects plus two- and three-factor interactions. The values $k = 1$ and $k = 2$ are equivalent to the 'linear' and 'interaction' specifications, respectively, while the value $k = N$ is equivalent to the 'full' specification.
- A matrix of term definitions having the same form as the input to the *x2fx* function. All entries must be 0 or 1 (no higher powers).

For more precise control over the main and interaction terms that *anovan* computes, *modeltype* can specify a matrix containing one row for each main or interaction term to include in the ANOVA model. Each row defines one term using a vector of N zeros and ones. The table below illustrates the coding for a 3-factor ANOVA.

Matrix Row	ANOVA Term
[1 0 0]	Main term A
[0 1 0]	Main term B

Matrix Row	ANOVA Term
[0 0 1]	Main term C
[1 1 0]	Interaction term AB
[1 0 1]	Interaction term AC
[0 1 1]	Interaction term BC
[1 1 1]	Interaction term ABC

For example, if *modeltype* is the matrix [0 1 0;0 0 1;0 1 1], the output vector *p* contains the *p*-values for the null hypotheses on the main effects B and C and the interaction effect BC, in that order. A simple way to generate the *modeltype* matrix is to modify the *terms* output, which codes the terms in the current model using the format described above. If *anovan* returns [0 1 0;0 0 1;0 1 1] for *terms*, for example, and there is no significant result for interaction BC, you can recompute the ANOVA on just the main effects B and C by specifying [0 1 0;0 0 1] for *modeltype*.

Sum of Squares

This section explains how to use the argument '*sstype*' with the syntax:

```
[...] = anovan(y,group, 'sstype', type)
```

This syntax computes the ANOVA using the type of sum of squares specified by *type*, which can be 1, 2, 3, or h. While the numbers 1 – 3 designate Type 1, Type 2, or Type 3 sum of squares, respectively, h represents a hierarchical model similar to type 2, but with continuous as well as categorical factors used to determine the hierarchy of terms. The default value is 3. For a model containing main effects but no interactions, the value of *type* only influences computations on unbalanced data.

The sum of squares for any term is determined by comparing two models. The Type 1 sum of squares for a term is the reduction in residual sum of squares obtained by adding that term to a fit that already includes the terms listed before it. The Type 2 sum of squares is

the reduction in residual sum of squares obtained by adding that term to a model consisting of all other terms that do not contain the term in question. The Type 3 sum of squares is the reduction in residual sum of squares obtained by adding that term to a model containing all other terms, but with their effects constrained to obey the usual “sigma restrictions” that make models estimable.

Suppose you are fitting a model with two factors and their interaction, and that the terms appear in the order A, B, AB . Let $R(\cdot)$ represent the residual sum of squares for a model, so for example $R(A, B, AB)$ is the residual sum of squares fitting the whole model, $R(A)$ is the residual sum of squares fitting just the main effect of A , and $R(1)$ is the residual sum of squares fitting just the mean. The three types of sums of squares are as follows:

Term	Type 1 Sum of Squares	Type 2 Sum of Squares	Type 3 Sum of Squares
A	$R(1) - R(A)$	$R(B) - R(A, B)$	$R(B, AB) - R(A, B, AB)$
B	$R(A) - R(A, B)$	$R(A) - R(A, B)$	$R(A, AB) - R(A, B, AB)$
AB	$R(A, B) - R(A, B, AB)$	$R(A, B) - R(A, B, AB)$	$R(A, B) - R(A, B, AB)$

The models for Type 3 sum of squares have sigma restrictions imposed. This means, for example, that in fitting $R(B, AB)$, the array of AB effects is constrained to sum to 0 over A for each value of B , and over B for each value of A .

Example of Three-Way ANOVA

As an example of three-way ANOVA, consider the vector y and group inputs below.

```

y = [52.7 57.5 45.9 44.5 53.0 57.0 45.9 44.0]';
g1 = [1 2 1 2 1 2 1 2];
g2 = {'hi'; 'hi'; 'lo'; 'lo'; 'hi'; 'hi'; 'lo'; 'lo'};
g3 = {'may'; 'may'; 'may'; 'may'; 'june'; 'june'; 'june'; 'june'};
    
```


This defines a three-way ANOVA with two levels of each factor. Every observation in y is identified by a combination of factor levels. If the factors are A, B, and C, then observation $y(1)$ is associated with

- Level 1 of factor A
- Level 'hi' of factor B
- Level 'may' of factor C

Similarly, observation $y(6)$ is associated with

- Level 2 of factor A
- Level 'hi' of factor B
- Level 'june' of factor C

To compute the ANOVA, enter

```
p = anovan(y, {g1 g2 g3})
p =
    0.4174
    0.0028
    0.9140
```

Output vector p contains p -values for the null hypotheses on the N main effects. Element $p(1)$ contains the p value for the null hypotheses, H_{0A} , that samples at all levels of factor A are drawn from the same population; element $p(2)$ contains the p value for the null hypotheses, H_{0B} , that samples at all levels of factor B are drawn from the same population; and so on.

If any p value is near zero, this casts doubt on the associated null hypothesis. For example, a sufficiently small p value for H_{0A} suggests that at least one A-sample mean is significantly different from the other A-sample means; that is, there is a main effect due to factor A. You need to choose a bound for the p value to determine whether a result is statistically significant. It is common to declare a result significant if the p value is less than 0.05 or 0.01.

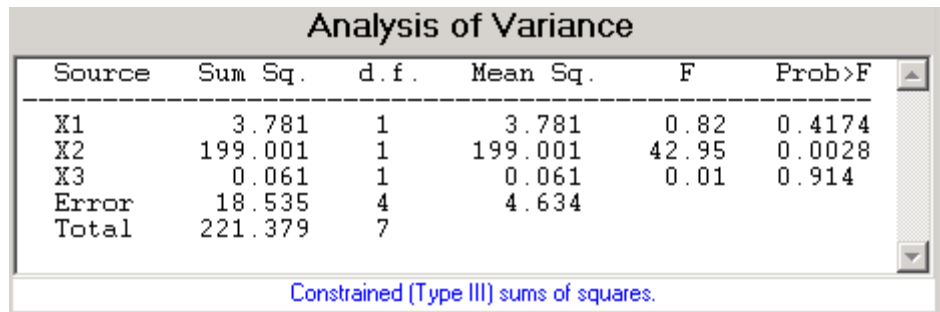
anovan also displays a figure showing the standard ANOVA table, which by default divides the variability of the data in x into

- The variability due to differences between the levels of each factor accounted for in the model (one row for each factor)
- The remaining variability not explained by any systematic source

The ANOVA table has six columns:

- The first shows the source of the variability.
- The second shows the sum of squares (SS) due to each source.
- The third shows the degrees of freedom (df) associated with each source.
- The fourth shows the mean squares (MS), which is the ratio SS/df.
- The fifth shows the F statistics, which are the ratios of the mean squares.
- The sixth shows the p -values for the F statistics.

The table is shown in the following figure:



Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
X1	3.781	1	3.781	0.82	0.4174
X2	199.001	1	199.001	42.95	0.0028
X3	0.061	1	0.061	0.01	0.914
Error	18.535	4	4.634		
Total	221.379	7			

Constrained (Type III) sums of squares.

Two-Factor Interactions

By default, anovan computes p -values just for the three main effects. To also compute p -values for the two-factor interactions, $X1*X2$, $X1*X3$, and $X2*X3$, add the name/value pair 'model', 'interaction' as input arguments.

```
p = anovan(y,{g1 g2 g3},'model','interaction')
p =
    0.0347
    0.0048
    0.2578
    0.0158
    0.1444
    0.5000
```

The first three entries of p are the p -values for the main effects. The last three entries are the p -values for the two-factor interactions. You can determine the order in which the two-factor interactions occur from the ANOVAN table shown in the following figure.

Source	Sum Sq.	d. f.	Mean Sq.	F	Prob>F
X1	3.781	1	3.781	336.11	0.0347
X2	199.001	1	199.001	17689	0.0048
X3	0.061	1	0.061	5.44	0.2578
X1*X2	18.301	1	18.301	1626.78	0.0158
X1*X3	0.211	1	0.211	18.78	0.1444
X2*X3	0.011	1	0.011	1	0.5
Error	0.011	1	0.011		
Total	221.379	7			

Constrained (Type III) sums of squares.

The Stats Structure

The `anovan` test evaluates the hypothesis that the different levels of a factor (or more generally, a term) have the same effect, against the alternative that they do not all have the same effect. Sometimes it is preferable to perform a test to determine which pairs of levels are significantly different, and which are not. Use the `multcompare` function to perform such tests by supplying the `stats` structure as input.

The `stats` structure contains the fields listed below, in addition to a number of other fields required for doing multiple comparisons using the `multcompare` function:

Field	Description
<code>coeffs</code>	Estimated coefficients
<code>coeffnames</code>	Name of term for each coefficient
<code>vars</code>	Matrix of grouping variable values for each term
<code>resid</code>	Residuals from the fitted model

The `stats` structure also contains the following fields if there are random effects:

Field	Description
<code>ems</code>	Expected mean squares
<code>denom</code>	Denominator definition
<code>rtnames</code>	Names of random terms
<code>varest</code>	Variance component estimates (one per random term)
<code>varci</code>	Confidence intervals for variance components

Examples

“Example: Two-Way ANOVA” on page 8-10 shows how to use `anova2` to analyze the effects of two factors on a response in a balanced design. For a design that is not balanced, use `anovan` instead.

The data in `carbig.mat` gives measurements on 406 cars. Use `anovan` to study how the mileage depends on where and when the cars were made:

```
load carbig

p = anovan(MPG,{org when},'model',2,'sstype',3,...
           'varnames',{'Origin';'Mfg date'})
p =
```

0
0
0.3059

Analysis of Variance					
Source	Sum Sq.	d.f.	Mean Sq.	F	Prob>F
Origin	5727.2	2	2863.58	115.09	0
Mfg date	4710.3	2	2355.15	94.65	0
Origin*Mfg date	120.5	4	30.12	1.21	0.3059
Error	9679.1	389	24.88		
Total	24252.6	397			

Constrained (Type III) sums of squares.

The p value for the interaction term is not small, indicating little evidence that the effect of the year or manufacture (*when*) depends on where the car was made (*org*). The linear effects of those two factors, however, are significant.

References

[1] Hogg, R. V., and J. Ledolter. *Engineering Statistics*. New York: MacMillan, 1987.

See Also

anova1 | anova2 | multcompare

Purpose

Ansari-Bradley test

Syntax

```
h = ansaribradley(x,y)
h = ansaribradley(x,y,alpha)
h = ansaribradley(x,y,alpha,tail)
[h,p] = ansaribradley(...)
[h,p,stats] = ansaribradley(...)
[...] = ansaribradley(x,y,alpha,tail,exact)
[...] = ansaribradley(x,y,alpha,tail,exact,dim)
```

Description

`h = ansaribradley(x,y)` performs an Ansari-Bradley test of the hypothesis that two independent samples, in the vectors `x` and `y`, come from the same distribution, against the alternative that they come from distributions that have the same median and shape but different dispersions (e.g. variances). The result is `h = 0` if the null hypothesis of identical distributions cannot be rejected at the 5% significance level, or `h = 1` if the null hypothesis can be rejected at the 5% level. `x` and `y` can have different lengths.

`x` and `y` can also be matrices or N -dimensional arrays. For matrices, `ansaribradley` performs separate tests along each column, and returns a vector of results. `x` and `y` must have the same number of columns. For N -dimensional arrays, `ansaribradley` works along the first nonsingleton dimension. `x` and `y` must have the same size along all the remaining dimensions.

`h = ansaribradley(x,y,alpha)` performs the test at the significance level ($100*\alpha$), where `alpha` is a scalar.

`h = ansaribradley(x,y,alpha,tail)` performs the test against the alternative hypothesis specified by the string `tail`. `tail` is one of:

- 'both' — Two-tailed test (dispersion parameters are not equal)
- 'right' — Right-tailed test (dispersion of X is greater than dispersion of Y)
- 'left' — Left-tailed test (dispersion of X is less than dispersion of Y)

`[h,p] = ansaribradley(...)` returns the p value, i.e., the probability of observing the given result, or one more extreme, by chance if the null hypothesis is true. Small values of p cast doubt on the validity of the null hypothesis.

`[h,p,stats] = ansaribradley(...)` returns a structure `stats` with the following fields:

- `W` — Value of the test statistic W , which is the sum of the Ansari-Bradley ranks for the X sample
- `Wstar` — Approximate normal statistic W^*

`[...] = ansaribradley(x,y,alpha,tail,exact)` computes p using an exact calculation of the distribution of W with `exact = 'on'`. This can be time-consuming for large samples. `exact = 'off'` computes p using a normal approximation for the distribution of W^* . The default if `exact` is empty is to use the exact calculation if N , the total number of rows in x and y , is 25 or less, and to use the normal approximation if $N > 25$. Pass in `[]` for `alpha` and `tail` to use their default values while specifying a value for `exact`. Note that N is computed before any NaN values (representing missing data) are removed.

`[...] = ansaribradley(x,y,alpha,tail,exact,dim)` works along dimension `dim` of x and y .

The Ansari-Bradley test is a nonparametric alternative to the two-sample F test of equal variances. It does not require the assumption that x and y come from normal distributions. The dispersion of a distribution is generally measured by its variance or standard deviation, but the Ansari-Bradley test can be used with samples from distributions that do not have finite variances.

The theory behind the Ansari-Bradley test requires that the groups have equal medians. Under that assumption and if the distributions in each group are continuous and identical, the test does not depend on the distributions in each group. If the groups do not have the same medians, the results may be misleading. Ansari and Bradley recommend subtracting the median in that case, but the distribution of the resulting test, under the null hypothesis, is no longer independent

of the common distribution of x and y . If you want to perform the tests with medians subtracted, you should subtract the medians from x and y before calling `ansaribradley`.

Examples

Is the dispersion significantly different for two model years?

```
load carsmall
[h,p,stats] = ansaribradley(MPG(Model_Year==82),MPG(Model_Year==76))
h =
    0
p =
    0.8426
stats =
    W: 526.9000
    Wstar: 0.1986
```

See Also

`vartest` | `vartestn` | `ttest2`

Purpose

Interactive analysis of covariance

Syntax

```
aocool(x,y,group)
aocool(x,y,group,alpha)
aocool(x,y,group,alpha,xname,yname,gname)
aocool(x,y,group,alpha,xname,yname,gname,displayopt)
aocool(x,y,group,alpha,xname,yname,gname,displayopt,model)
h = aocool(...)
[h,atab,ctab] = aocool(...)
[h,atab,ctab,stats] = aocool(...)
```

Description

`aocool(x,y,group)` fits a separate line to the column vectors, `x` and `y`, for each group defined by the values in the array `group`. `group` may be a categorical variable, vector, character array, or cell array of strings. These types of models are known as one-way analysis of covariance (ANOCOVA) models. The output consists of three figures:

- An interactive graph of the data and prediction curves
- An ANOVA table
- A table of parameter estimates

You can use the figures to change models and to test different parts of the model. More information about interactive use of the `aocool` function appears in “Analysis of Covariance Tool” on page 8-27.

`aocool(x,y,group,alpha)` determines the confidence levels of the prediction intervals. The confidence level is $100(1-\alpha)\%$. The default value of `alpha` is 0.05.

`aocool(x,y,group,alpha,xname,yname,gname)` specifies the name to use for the `x`, `y`, and `g` variables in the graph and tables. If you enter simple variable names for the `x`, `y`, and `g` arguments, the `aocool` function uses those names. If you enter an expression for one of these arguments, you can specify a name to use in place of that expression by supplying these arguments. For example, if you enter `m(:,2)` as the `x` argument, you might choose to enter `'Col 2'` as the `xname` argument.

`aoctool(x,y,group,alpha,xname,yname,gname,displayopt)` enables the graph and table displays when *displayopt* is 'on' (default) and suppresses those displays when *displayopt* is 'off'.

`aoctool(x,y,group,alpha,xname,yname,gname,displayopt,model)` specifies the initial model to fit. The value of *model* can be any of the following:

- 'same mean' — Fit a single mean, ignoring grouping
- 'separate means' — Fit a separate mean to each group
- 'same line' — Fit a single line, ignoring grouping
- 'parallel lines' — Fit a separate line to each group, but constrain the lines to be parallel
- 'separate lines' — Fit a separate line to each group, with no constraints

`h = aoctool(...)` returns a vector of handles to the line objects in the plot.

`[h,atab,ctab] = aoctool(...)` returns cell arrays containing the entries in ANOVA table (*atab*) and the table of coefficient estimates (*ctab*). (You can copy a text version of either table to the clipboard by using the Copy Text item on the **Edit** menu.)

`[h,atab,ctab,stats] = aoctool(...)` returns a *stats* structure that you can use to perform a follow-up multiple comparison test. The ANOVA table output includes tests of the hypotheses that the slopes or intercepts are all the same, against a general alternative that they are not all the same. Sometimes it is preferable to perform a test to determine which pairs of values are significantly different, and which are not. You can use the `multcompare` function to perform such tests by supplying the *stats* structure as input. You can test either the slopes, the intercepts, or population marginal means (the heights of the curves at the mean *x* value).

Examples

This example illustrates how to fit different models non-interactively. After loading the smaller car data set and fitting a separate-slopes model, you can examine the coefficient estimates.

```
load carsmall
[h,a,c,s] = aoctool(Weight,MPG,Model_Year,0.05,...
                   '', '', '', 'off', 'separate lines');
c(:,1:2)
ans =
    'Term'      'Estimate'
    'Intercept' [45.97983716833132]
    ' 70'       [-8.58050531454973]
    ' 76'       [-3.89017396094922]
    ' 82'       [12.47067927549897]
    'Slope'     [-0.00780212907455]
    ' 70'       [ 0.00195840368824]
    ' 76'       [ 0.00113831038418]
    ' 82'       [-0.00309671407243]
```

Roughly speaking, the lines relating MPG to Weight have an intercept close to 45.98 and a slope close to -0.0078. Each group's coefficients are offset from these values somewhat. For instance, the intercept for the cars made in 1970 is $45.98 - 8.58 = 37.40$.

Next, try a fit using parallel lines. (The ANOVA table shows that the parallel-lines fit is significantly worse than the separate-lines fit.)

```
[h,a,c,s] = aoctool(Weight,MPG,Model_Year,0.05,...
                   '', '', '', 'off', 'parallel lines');
c(:,1:2)
ans =
    'Term'      'Estimate'
    'Intercept' [43.38984085130596]
    ' 70'       [-3.27948192983761]
    ' 76'       [-1.35036234809006]
```

```
' 82'      [ 4.62984427792768]  
'Slope'    [-0.00664751826198]
```

Again, there are different intercepts for each group, but this time the slopes are constrained to be the same.

See Also

`anova1` | `multcompare` | `polytool`

Purpose Append new trees to ensemble

Syntax `B = append(B, other)`

Description `B = append(B, other)` appends the trees from the `other` ensemble to those in `B`. This method checks for consistency of the `X` and `Y` properties of the two ensembles, as well as consistency of their compact objects and out-of-bag indices, before appending the trees. The output ensemble `B` takes training parameters such as `FBoot`, `Prior`, `Cost`, and `other` from the `B` input. There is no attempt to check if these training parameters are consistent between the two objects.

See Also `CompactTreeBagger.combine`

ProbDistKernel.BandWidth property

Purpose	Read-only value specifying bandwidth of kernel smoothing function for ProbDistKernel object
Description	BandWidth is a read-only property of the ProbDistKernel class. BandWidth is a value specifying the width of the kernel smoothing function used to compute a nonparametric estimate of the probability distribution when creating a ProbDistKernel object.
Values	<p>For a distribution specified to cover only the positive numbers or only a finite interval, the data are transformed before the kernel density is applied, and the bandwidth is on the scale of the transformed data.</p> <p>Use this information to view and compare the width of the kernel smoothing function used to create distributions.</p>
See Also	<code>ksdensity</code>

Purpose Bartlett's test

Syntax `ndim = barttest(X,alpha)`
`[ndim,prob,chisquare] = barttest(X,alpha)`

Description `ndim = barttest(X,alpha)` returns the number of dimensions necessary to explain the nonrandom variation in the data matrix X , using the significance probability α . The dimension is determined by a series of hypothesis tests. The test for `ndim=1` tests the hypothesis that the variances of the data values along each principal component are equal, the test for `ndim=2` tests the hypothesis that the variances along the second through last components are equal, and so on.

`[ndim,prob,chisquare] = barttest(X,alpha)` returns the number of dimensions, the significance values for the hypothesis tests, and the χ^2 values associated with the tests.

Examples

```
X = mvnrnd([0 0],[1 0.99; 0.99 1],20);
X(:,3:4) = mvnrnd([0 0],[1 0.99; 0.99 1],20);
X(:,5:6) = mvnrnd([0 0],[1 0.99; 0.99 1],20);
[ndim, prob] = barttest(X,0.05)
ndim =
     3
prob =
     0
     0
     0
    0.5081
    0.6618
```

See Also `pca` | `pcacov` | `pcares`

bbdesign

Purpose Box-Behnken design

Syntax
`dBB = bbdesign(n)`
`[dBB,blocks] = bbdesign(n)`
`[...] = bbdesign(n,param,val)`

Description `dBB = bbdesign(n)` generates a Box-Behnken design for n factors. n must be an integer 3 or larger. The output matrix `dBB` is m -by- n , where m is the number of runs in the design. Each row represents one run, with settings for all factors represented in the columns. Factor values are normalized so that the cube points take values between -1 and 1.

`[dBB,blocks] = bbdesign(n)` requests a blocked design. The output `blocks` is an m -by-1 vector of block numbers for each run. Blocks indicate runs that are to be measured under similar conditions to minimize the effect of inter-block differences on the parameter estimates.

`[...] = bbdesign(n,param,val)` specifies one or more optional parameter/value pairs for the design. The following table lists valid parameter/value pairs.

Parameter	Description	Values
'center'	Number of center points.	Integer. The default depends on n .
'blocksize'	Maximum number of points per block.	Integer. The default is Inf.

Examples

The following creates a 3-factor Box-Behnken design:

```
dBB = bbdesign(3)
dBB =
    -1    -1     0
    -1     1     0
     1    -1     0
```



```

1      1      0
-1     0     -1
-1     0      1
1      0     -1
1      0      1
0     -1     -1
0     -1      1
0      1     -1
0      1      1
0      0      0
0      0      0
0      0      0

```

The center point is run 3 times to allow for a more uniform estimate of the prediction variance over the entire design space.

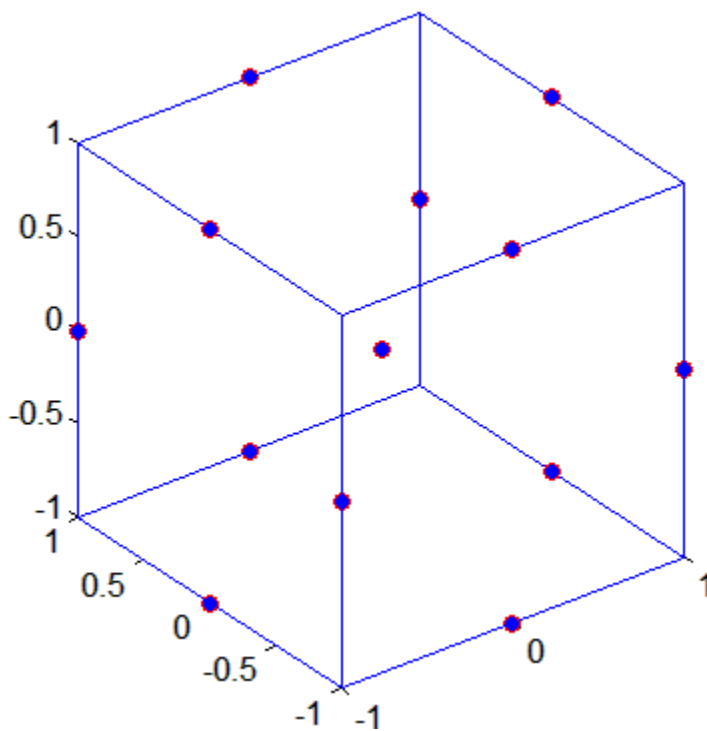
Visualize the design as follows:

```

plot3(dBB(:,1),dBB(:,2),dBB(:,3),'ro',...
      'MarkerFaceColor','b')
X = [1 -1 -1 -1 1 -1 -1 -1 1 1 -1 -1; ...
     1 1 1 -1 1 1 1 -1 1 1 -1 -1];
Y = [-1 -1 1 -1 -1 -1 1 -1 1 -1 1 -1; ...
     1 -1 1 1 1 -1 1 1 1 -1 1 -1];
Z = [1 1 1 1 -1 -1 -1 -1 -1 -1 -1 -1; ...
     1 1 1 1 -1 -1 -1 -1 1 1 1 1];
line(X,Y,Z,'Color','b')
axis square equal

```

bbdesign



See Also

`ccdesign`

Purpose Beta cumulative distribution function

Syntax `p = betacdf(X,A,B)`

Description `p = betacdf(X,A,B)` returns the beta cdf at each of the values in `X` using the corresponding parameters in `A` and `B`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `A` and `B` must all be positive, and the values in `X` must lie on the interval `[0,1]`.

The beta cdf for a given value `x` and given pair of parameters `a` and `b` is

$$p = F(x | a, b) = \frac{1}{B(a, b)} \int_0^x t^{a-1} (1-t)^{b-1} dt$$

where $B(\cdot)$ is the Beta function.

Examples

```
x = 0.1:0.2:0.9;
a = 2;
b = 2;
p = betacdf(x, a, b)
p =
    0.0280    0.2160    0.5000    0.7840    0.9720
```

```
a = [1 2 3];
p = betacdf(0.5, a, a)
p =
    0.5000    0.5000    0.5000
```

See Also `cdf` | `betapdf` | `betainv` | `betastat` | `betalike` | `betarnd` | `betafit`

How To • “Beta Distribution” on page B-4

betafit

Purpose Beta parameter estimates

Syntax
`phat = betafit(data)`
`[phat,pci] = betafit(data,alpha)`

Description `phat = betafit(data)` computes the maximum likelihood estimates of the beta distribution parameters a and b from the data in the vector `data` and returns a column vector containing the a and b estimates, where the beta cdf is given by

$$F(x | a, b) = \frac{1}{B(a, b)} \int_0^x t^{a-1} (1-t)^{b-1} dt$$

and $B(\cdot)$ is the Beta function. The elements of `data` must lie in the open interval $(0, 1)$, where the beta distribution is defined. However, it is sometimes also necessary to fit a beta distribution to data that include exact zeros or ones. For such data, the beta likelihood function is unbounded, and standard maximum likelihood estimation is not possible. In that case, `betafit` maximizes a modified likelihood that incorporates the zeros or ones by treating them as if they were values that have been left-censored at `sqrt(realmin)` or right-censored at `1-eps/2`, respectively.

`[phat,pci] = betafit(data,alpha)` returns confidence intervals on the a and b parameters in the 2-by-2 matrix `pci`. The first column of the matrix contains the lower and upper confidence bounds for parameter a , and the second column contains the confidence bounds for parameter b . The optional input argument `alpha` is a value in the range $[0, 1]$ specifying the width of the confidence intervals. By default, `alpha` is 0.05, which corresponds to 95% confidence intervals. The confidence intervals are based on a normal approximation for the distribution of the logs of the parameter estimates.

Examples This example generates 100 beta distributed observations. The true a and b parameters are 4 and 3, respectively. Compare these to the

values returned in `p` by the beta fit. Note that the columns of `ci` both bracket the true parameters.

```
data = betarnd(4,3,100,1);
[p,ci] = betafit(data,0.01)
p =
    5.5328    3.8097
ci =
    3.6538    2.6197
    8.3781    5.5402
```

References

[1] Hahn, Gerald J., and S. S. Shapiro. *Statistical Models in Engineering*. Hoboken, NJ: John Wiley & Sons, Inc., 1994, p. 95.

See Also

`mle` | `betapdf` | `betainv` | `betastat` | `betalike` | `betarnd` | `betacdf`

How To

- “Beta Distribution” on page B-4

betainv

Purpose Beta inverse cumulative distribution function

Syntax `X = betainv(P,A,B)`

Description `X = betainv(P,A,B)` computes the inverse of the beta cdf with parameters specified by A and B for the corresponding probabilities in P. P, A, and B can be vectors, matrices, or multidimensional arrays that are all the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in A and B must all be positive, and the values in P must lie on the interval [0, 1].

The inverse beta cdf for a given probability p and a given pair of parameters a and b is

$$x = F^{-1}(p | a, b) = \{x : F(x | a, b) = p\}$$

where

$$p = F(x | a, b) = \frac{1}{B(a, b)} \int_0^x t^{a-1} (1-t)^{b-1} dt$$

and $B(\cdot)$ is the Beta function. Each element of output X is the value whose cumulative probability under the beta cdf defined by the corresponding parameters in A and B is specified by the corresponding value in P.

Algorithms The `betainv` function uses Newton's method with modifications to constrain steps to the allowable range for x , i.e., [0 1].

Examples

```
p = [0.01 0.5 0.99];  
x = betainv(p,10,5)  
x =  
    0.3726    0.6742    0.8981
```

According to this result, for a beta cdf with $a = 10$ and $b = 5$, a value less than or equal to 0.3726 occurs with probability 0.01. Similarly,

values less than or equal to 0.6742 and 0.8981 occur with respective probabilities 0.5 and 0.99.

See Also

`icdf` | `betapdf` | `betafit` | `betainv` | `betastat` | `betalike` | `betarnd`
| `betacdf`

How To

- “Beta Distribution” on page B-4

betalike

Purpose Beta negative log-likelihood

Syntax
`nlogL = betalike(params,data)`
`[nlogL,AVAR] = betalike(params,data)`

Description `nlogL = betalike(params,data)` returns the negative of the beta log-likelihood function for the beta parameters a and b specified in vector `params` and the observations specified in the column vector `data`.

The elements of `data` must lie in the open interval $(0, 1)$, where the beta distribution is defined. However, it is sometimes also necessary to fit a beta distribution to data that include exact zeros or ones. For such data, the beta likelihood function is unbounded, and standard maximum likelihood estimation is not possible. In that case, `betalike` computes a modified likelihood that incorporates the zeros or ones by treating them as if they were values that have been left-censored at `sqrt(realmin)` or right-censored at `1-eps/2`, respectively.

`[nlogL,AVAR] = betalike(params,data)` also returns `AVAR`, which is the asymptotic variance-covariance matrix of the parameter estimates if the values in `params` are the maximum likelihood estimates. `AVAR` is the inverse of Fisher's information matrix. The diagonal elements of `AVAR` are the asymptotic variances of their respective parameters.

`betalike` is a utility function for maximum likelihood estimation of the beta distribution. The likelihood assumes that all the elements in the data sample are mutually independent. Since `betalike` returns the negative beta log-likelihood function, minimizing `betalike` using `fminsearch` is the same as maximizing the likelihood.

Examples This example continues the `betafit` example, which calculates estimates of the beta parameters for some randomly generated beta distributed data.

```
r = betarnd(4,3,100,1);  
[nlogl,AVAR] = betalike(betafit(r),r)  
nlogl =
```


-27.5996

AVAR =

0.2783	0.1316
0.1316	0.0867

See Also

[betapdf](#) | [betafit](#) | [betainv](#) | [betastat](#) | [betarnd](#) | [betacdf](#)

How To

- “Beta Distribution” on page B-4

betapdf

Purpose Beta probability density function

Syntax `Y = betapdf(X,A,B)`

Description `Y = betapdf(X,A,B)` computes the beta pdf at each of the values in `X` using the corresponding parameters in `A` and `B`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions of the other inputs. The parameters in `A` and `B` must all be positive, and the values in `X` must lie on the interval `[0, 1]`.

The beta probability density function for a given value x and given pair of parameters a and b is

$$y = f(x | a, b) = \frac{1}{B(a, b)} x^{a-1} (1-x)^{b-1} I_{(0,1)}(x)$$

where $B(\cdot)$ is the Beta function. The indicator function $I_{(0,1)}(x)$ ensures that only values of x in the range $(0, 1)$ have nonzero probability. The uniform distribution on $(0, 1)$ is a degenerate case of the beta pdf where $a = 1$ and $b = 1$.

A *likelihood function* is the pdf viewed as a function of the parameters. Maximum likelihood estimators (MLEs) are the values of the parameters that maximize the likelihood function for a fixed value of x .

Examples

```
a = [0.5 1; 2 4]
a =
    0.5000    1.0000
    2.0000    4.0000
y = betapdf(0.5, a, a)
y =
    0.6366    1.0000
    1.5000    2.1875
```

See Also pdf | betafit | betainv | betastat | betalike | betarnd | betacdf

How To

- “Beta Distribution” on page B-4

betarnd

Purpose Beta random numbers

Syntax
R = betarnd(A,B)
R = betarnd(A,B,m,n,...)
R = betarnd(A,B,[m,n,...])

Description R = betarnd(A,B) generates random numbers from the beta distribution with parameters specified by A and B. A and B can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of R. A scalar input for A or B is expanded to a constant array with the same dimensions as the other input.

R = betarnd(A,B,m,n,...) or R = betarnd(A,B,[m,n,...]) generates an m-by-n-by-... array containing random numbers from the beta distribution with parameters A and B. A and B can each be scalars or arrays of the same size as R.

Examples

```
a = [1 1;2 2];  
b = [1 2;1 2];  
  
r = betarnd(a,b)  
r =  
    0.6987    0.6139  
    0.9102    0.8067  
  
r = betarnd(10,10,[1 5])  
r =  
    0.5974    0.4777    0.5538    0.5465    0.6327  
  
r = betarnd(4,2,2,3)  
r =  
    0.3943    0.6101    0.5768  
    0.5990    0.2760    0.5474
```

See Also random | betapdf | betafit | betainv | betastat | betalike | betacdf

How To

- “Beta Distribution” on page B-4

betastat

Purpose Beta mean and variance

Syntax `[M,V] = betastat(A,B)`

Description `[M,V] = betastat(A,B)`, with $A > 0$ and $B > 0$, returns the mean of and variance for the beta distribution with parameters specified by A and B . A and B can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of M and V . A scalar input for A or B is expanded to a constant array with the same dimensions as the other input.

The mean of the beta distribution with parameters a and b is $a / (a + b)$ and the variance is

$$\frac{ab}{(a+b+1)(a+b)^2}$$

Examples If parameters a and b are equal, the mean is $1/2$.

```
a = 1:6;
[m,v] = betastat(a,a)
m =
    0.5000    0.5000    0.5000    0.5000    0.5000    0.5000
v =
    0.0833    0.0500    0.0357    0.0278    0.0227    0.0192
```

See Also `betapdf` | `betafit` | `betainv` | `betalike` | `betarnd` | `betacdf`

How To • “Beta Distribution” on page B-4

Purpose Bayes Information Criterion

Description The Bayes Information Criterion: $2 \cdot N \log L + m \cdot \log(n)$, where n is the number of observations and m is the number of estimated parameters.

binocdf

Purpose Binomial cumulative distribution function

Syntax `Y = binocdf(X,N,P)`

Description `Y = binocdf(X,N,P)` computes a binomial cdf at each of the values in `X` using the corresponding number of trials in `N` and probability of success for each trial in `P`. `X`, `N`, and `P` can be vectors, matrices, or multidimensional arrays that are all the same size. A scalar input is expanded to a constant array with the same dimensions of the other inputs. The values in `N` must all be positive integers, the values in `X` must lie on the interval `[0,N]`, and the values in `P` must lie on the interval `[0, 1]`.

The binomial cdf for a given value x and a given pair of parameters n and p is

$$y = F(x | n, p) = \sum_{i=0}^x \binom{n}{i} p^i (1-p)^{(n-i)} I_{(0,1,\dots,n)}(i).$$

The result, y , is the probability of observing up to x successes in n independent trials, where the probability of success in any given trial is p . The indicator function $I_{(0,1,\dots,n)}(i)$ ensures that x only adopts values of $0,1,\dots,n$.

Examples

If a baseball team plays 162 games in a season and has a 50-50 chance of winning any game, then the probability of that team winning more than 100 games in a season is:

```
1 - binocdf(100,162,0.5)
```

The result is 0.001 (i.e., $1 - 0.999$). If a team wins 100 or more games in a season, this result suggests that it is likely that the team's true probability of winning any game is greater than 0.5.

See Also

`cdf` | `binopdf` | `binoinv` | `binostat` | `binofit` | `binornd`

How To

- “Binomial Distribution” on page B-7

binofit

Purpose

Binomial parameter estimates

Syntax

```
phat = binofit(x,n)
[phat,pci] = binofit(x,n)
[phat,pci] = binofit(x,n,alpha)
```

Description

`phat = binofit(x,n)` returns a maximum likelihood estimate of the probability of success in a given binomial trial based on the number of successes, `x`, observed in `n` independent trials. If `x = (x(1), x(2), ... x(k))` is a vector, `binofit` returns a vector of the same size as `x` whose `i`th entry is the parameter estimate for `x(i)`. All `k` estimates are independent of each other. If `n = (n(1), n(2), ..., n(k))` is a vector of the same size as `x`, the binomial fit, `binofit`, returns a vector whose `i`th entry is the parameter estimate based on the number of successes `x(i)` in `n(i)` independent trials. A scalar value for `x` or `n` is expanded to the same size as the other input.

`[phat,pci] = binofit(x,n)` returns the probability estimate, `phat`, and the 95% confidence intervals, `pci`. `binofit` uses the Clopper-Pearson method to calculate confidence intervals.

`[phat,pci] = binofit(x,n,alpha)` returns the $100(1 - \text{alpha})\%$ confidence intervals. For example, `alpha = 0.01` yields 99% confidence intervals.

Note `binofit` behaves differently than other Statistics Toolbox functions that compute parameter estimates, in that it returns independent estimates for each entry of `x`. By comparison, `expfit` returns a single parameter estimate based on all the entries of `x`.

Unlike most other distribution fitting functions, the `binofit` function treats its input `x` vector as a collection of measurements from separate samples. If you want to treat `x` as a single sample and compute a single parameter estimate for it, you can use `binofit(sum(x),sum(n))` when `n` is a vector, and `binofit(sum(X),N*length(X))` when `n` is a scalar.

Examples

This example generates a binomial sample of 100 elements, where the probability of success in a given trial is 0.6, and then estimates this probability from the outcomes in the sample.

```
r = binornd(100,0.6);  
[phat,pci] = binofit(r,100)  
phat =  
    0.5800  
pci =  
    0.4771    0.6780
```

The 95% confidence interval, `pci`, contains the true value, 0.6.

References

[1] Johnson, N. L., S. Kotz, and A. W. Kemp. *Univariate Discrete Distributions*. Hoboken, NJ: Wiley-Interscience, 1993.

See Also

`mle` | `binopdf` | `binocdf` | `binoinv` | `binostat` | `binornd`

How To

- “Binomial Distribution” on page B-7

binoinv

Purpose Binomial inverse cumulative distribution function

Syntax `X = binoinv(Y,N,P)`

Description `X = binoinv(Y,N,P)` returns the smallest integer X such that the binomial cdf evaluated at X is equal to or exceeds Y . You can think of Y as the probability of observing X successes in N independent trials where P is the probability of success in each trial. Each X is a positive integer less than or equal to N .

Y , N , and P can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in N must be positive integers, and the values in both P and Y must lie on the interval $[0\ 1]$.

Examples If a baseball team has a 50-50 chance of winning any game, what is a reasonable range of games this team might win over a season of 162 games?

```
binoinv([0.05 0.95],162,0.5)
ans =
    71    91
```

This result means that in 90% of baseball seasons, a .500 team should win between 71 and 91 games.

See Also `icdf` | `binopdf` | `binocdf` | `binofit` | `binostat` | `binornd`

How To • “Binomial Distribution” on page B-7

Purpose Binomial probability density function

Syntax `Y = binopdf(X,N,P)`

Description `Y = binopdf(X,N,P)` computes the binomial pdf at each of the values in `X` using the corresponding number of trials in `N` and probability of success for each trial in `P`. `Y`, `N`, and `P` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions of the other inputs.

The parameters in `N` must be positive integers, and the values in `P` must lie on the interval $[0, 1]$.

The binomial probability density function for a given value x and given pair of parameters n and p is

$$y = f(x | n, p) = \binom{n}{x} p^x q^{(n-x)} I_{(0,1,\dots,n)}(x)$$

where $q = 1 - p$. The result, y , is the probability of observing x successes in n independent trials, where the probability of success in any *given* trial is p . The indicator function $I_{(0,1,\dots,n)}(x)$ ensures that x only adopts values of 0, 1, ..., n .

Examples

A Quality Assurance inspector tests 200 circuit boards a day. If 2% of the boards have defects, what is the probability that the inspector will find no defective boards on any given day?

```
binopdf(0,200,0.02)
ans =
    0.0176
```

What is the most likely number of defective boards the inspector will find?

```
defects=0:200;
y = binopdf(defects,200,.02);
```

binopdf

```
[x,i]=max(y);  
defects(i)  
ans =  
    4
```

See Also

pdf | binoinv | binocdf | binofit | binostat | binornd

How To

- “Binomial Distribution” on page B-7

Purpose	Binomial random numbers
Syntax	<pre>R = binornd(N,P) R = binornd(N,P,m,n,...) R = binornd(N,P,[m,n,...])</pre>
Description	<p><code>R = binornd(N,P)</code> generates random numbers from the binomial distribution with parameters specified by the number of trials, <code>N</code>, and probability of success for each trial, <code>P</code>. <code>N</code> and <code>P</code> can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of <code>R</code>. A scalar input for <code>N</code> or <code>P</code> is expanded to a constant array with the same dimensions as the other input.</p> <p><code>R = binornd(N,P,m,n,...)</code> or <code>R = binornd(N,P,[m,n,...])</code> generates an <code>m</code>-by-<code>n</code>-by-... array containing random numbers from the binomial distribution with parameters <code>N</code> and <code>P</code>. <code>N</code> and <code>P</code> can each be scalars or arrays of the same size as <code>R</code>.</p>
Algorithms	The <code>binornd</code> function uses the direct method using the definition of the binomial distribution as a sum of Bernoulli random variables.
Examples	<pre>n = 10:10:60; r1 = binornd(n,1./n) r1 = 2 1 0 1 1 2 r2 = binornd(n,1./n,[1 6]) r2 = 0 1 2 1 3 1 r3 = binornd(n,1./n,1,6) r3 = 0 1 1 1 0 3</pre>
See Also	<code>random</code> <code>binoinv</code> <code>binocdf</code> <code>binofit</code> <code>binostat</code> <code>binopdf</code>

binornd

How To

- “Binomial Distribution” on page B-7

Purpose Binomial mean and variance

Syntax `[M,V] = binostat(N,P)`

Description `[M,V] = binostat(N,P)` returns the mean of and variance for the binomial distribution with parameters specified by the number of trials, `N`, and probability of success for each trial, `P`. `N` and `P` can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of `M` and `V`. A scalar input for `N` or `P` is expanded to a constant array with the same dimensions as the other input.

The mean of the binomial distribution with parameters n and p is np . The variance is npq , where $q = 1-p$.

Examples

```
n = logspace(1,5,5)
n =
    10    100   1000  10000 100000
```

```
[m,v] = binostat(n,1./n)
m =
    1    1    1    1    1
v =
    0.9000  0.9900  0.9990  0.9999  1.0000
```

```
[m,v] = binostat(n,1/2)
m =
    5    50   500  5000 50000
v =
    1.0e+04 *
    0.0003  0.0025  0.0250  0.2500  2.5000
```

See Also `binoinv` | `binocdf` | `binofit` | `binornd` | `binopdf`

How To • “Binomial Distribution” on page B-7

biplot

Purpose

Biplot

Syntax

```
biplot(coefs)
h = biplot(coefs, 'Name', Value)
```

Description

`biplot(coefs)` creates a biplot of the coefficients in the matrix `coefs`. The biplot is 2-D if `coefs` has two columns or 3-D if it has three columns. `coefs` usually contains principal component coefficients created with `pca`, `pcacov`, or factor loadings estimated with `factoran`. The axes in the biplot represent the principal components or latent factors (columns of `coefs`), and the observed variables (rows of `coefs`) are represented as vectors.

A biplot allows you to visualize the magnitude and sign of each variable's contribution to the first two or three principal components, and how each observation is represented in terms of those components.

`biplot` imposes a sign convention, forcing the element with largest magnitude in each column of `coefs` to be positive. This flips some of the vectors in `coefs` to the opposite direction, but often makes the plot easier to read. Interpretation of the plot is unaffected, because changing the sign of a coefficient vector does not change its meaning.

`biplot` scales the scores so that they fit on the plot: It divides each score by the maximum absolute value of all scores, and multiplies by the maximum coefficient length of `coefs`. Then `biplot` changes the sign of score coordinates according to the sign convention for the `coefs`.

`h = biplot(coefs, 'Name', Value)` specifies one or more name/value input pairs and returns a column vector of handles to the graphics objects created by `biplot`. The `h` contains, in order, handles corresponding to variables (line handles, followed by marker handles, followed by text handles), to observations (if present, marker handles followed by text handles), and to the axis lines.

Input Arguments

Name-Value Pair Arguments

Scores

Plots both `coefs` and the `scores` in the matrix `scores` in the biplot. `scores` usually contains principal component scores created with `pca` or factor scores estimated with `factoran`. Each observation (row of scores) is represented as a point in the biplot.

VarLabels

Labels each vector (variable) with the text in the character array or cell array `varlabels`.

ObsLabels

Uses the text in the character array or cell array `obslabels` as observation names when displaying data cursors.

Positive

- `'true'` — restricts the biplot to the positive quadrant (in 2-D) or octant (in 3-D).
- `'false'` — makes the biplot over the range $\pm \max(\text{coefs}(:))$ for all coordinates.

Default: `false`

PropertyName

Specifies optional property name/value pairs for all line graphics objects created by `biplot`.

Examples

Perform a principal component analysis of the data in `carsmall.mat`:

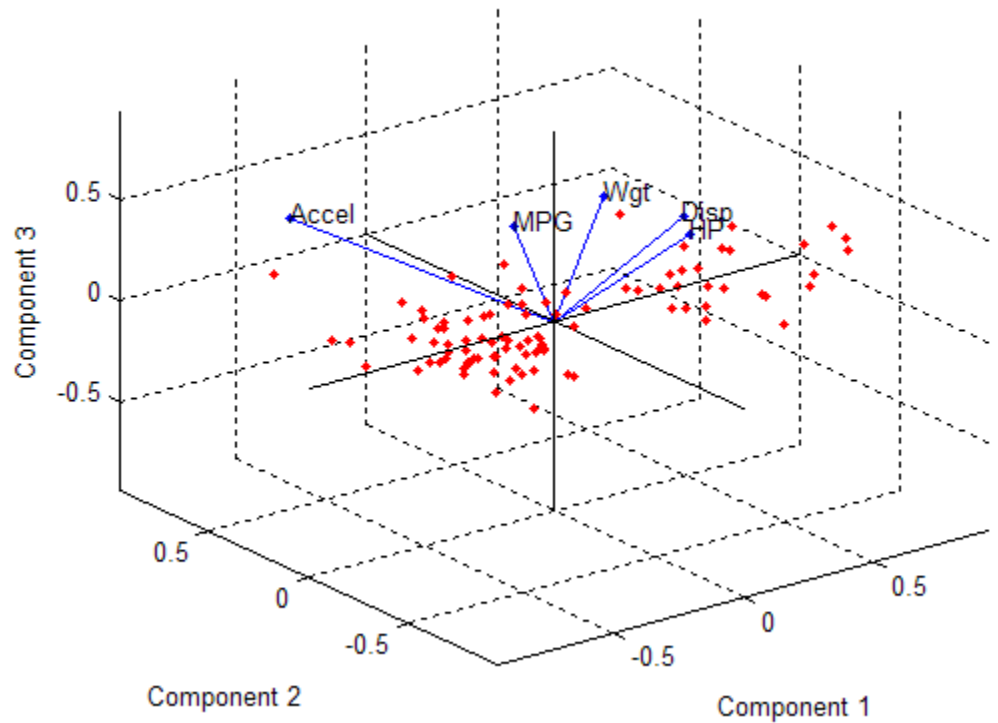
```
load carsmall
x = [Acceleration Displacement Horsepower MPG Weight];
x = x(all(~isnan(x),2),:);

[coefs,score] = pca(zscore(x));
```

biplot

View the data and the original variables in the space of the first three principal components:

```
vbls = {'Accel','Disp','HP','MPG','Wgt'};  
biplot(coefs(:,1:3),'scores',score(:,1:3),...  
       'varlabels',vbls);
```



See Also

[factoran](#) | [nmf](#) | [pca](#) | [pcacov](#) | [rotatefactors](#)

Purpose

Bootstrap confidence interval

Syntax

```
ci = bootci(nboot,bootfun,...)
ci = bootci(nboot,{bootfun,...},'alpha',alpha)
ci = bootci(nboot,{bootfun,...},...,'type',type)
ci = bootci(nboot,{bootfun,...},...,'type','student',
  'nbootstd',nbootstd)
ci = bootci(nboot,{bootfun,...},...,'type','student','stderr',
  stderr)
ci = bootci(nboot,{bootfun,...},...,'Weights',weights)
ci = bootci(nboot,{bootfun,...},...,'Options',options)
[ci,bootstat] = bootci(...)
```

Description

`ci = bootci(nboot,bootfun,...)` computes the 95% bootstrap confidence interval of the statistic computed by the function `bootfun`. `nboot` is a positive integer indicating the number of bootstrap samples used in the computation. `bootfun` is a function handle specified with `@`, and must return a scalar. The third and later input arguments to `bootci` are data (scalars, column vectors, or matrices) that are used to create inputs to `bootfun`. `bootci` creates each bootstrap sample by sampling with replacement from the rows of the non-scalar data arguments (these must have the same number of rows). Scalar data are passed to `bootfun` unchanged.

If `bootfun` returns a scalar, `ci` is a vector containing the lower and upper bounds of the confidence interval. If `bootfun` returns a vector of length m , `ci` is an array of size 2-by- m , where `ci(1,:)` are lower bounds and `ci(2,:)` are upper bounds. If `bootfun` returns an array of size m -by- n -by- p -by-..., `ci` is an array of size 2-by- m -by- n -by- p -by-..., where `ci(1,:,:,:,...)` is an array of lower bounds and `ci(2,:,:,:,...)` is an array of upper bounds.

`ci = bootci(nboot,{bootfun,...},'alpha',alpha)` computes the $100*(1-\alpha)$ bootstrap confidence interval of the statistic defined by the function `bootfun`. `bootfun` and the data that `bootci` passes to it are contained in a single cell array. `alpha` is a scalar between 0 and 1. The default value of `alpha` is 0.05.

`ci = bootci(nboot, {bootfun, ...}, ..., 'type', type)` computes the bootstrap confidence interval of the statistic defined by the function `bootfun`. `type` is the confidence interval type, chosen from among the following strings:

- `'norm'` or `'normal'` — Normal approximated interval with bootstrapped bias and standard error.
- `'per'` or `'percentile'` — Basic percentile method.
- `'cper'` or `'corrected percentile'` — Bias corrected percentile method.
- `'bca'` — Bias corrected and accelerated percentile method. This is the default.
- `'stud'` or `'student'` — Studentized confidence interval.

`ci = bootci(nboot, {bootfun, ...}, ..., 'type', 'student', 'nbootstd', nbootstd)` computes the studentized bootstrap confidence interval of the statistic defined by the function `bootfun`. The standard error of the bootstrap statistics is estimated using bootstrap, with `nbootstd` bootstrap data samples. `nbootstd` is a positive integer value. The default value of `nbootstd` is 100.

`ci = bootci(nboot, {bootfun, ...}, ..., 'type', 'student', 'stderr', stderr)` computes the studentized bootstrap confidence interval of statistics defined by the function `bootfun`. The standard error of the bootstrap statistics is evaluated by the function `stderr`. `stderr` is a function handle. `stderr` takes the same arguments as `bootfun` and returns the standard error of the statistic computed by `bootfun`.

`ci = bootci(nboot, {bootfun, ...}, ..., 'Weights', weights)` specifies observation weights. `weights` must be a vector of non-negative numbers with at least one positive element. The number of elements in `weights` must be equal to the number of rows in non-scalar input arguments to `bootfun`. To obtain one bootstrap replicate, `bootstrp` samples N out of N with replacement using these weights as multinomial sampling probabilities.

`ci = bootci(nboot,{bootfun,...},...,'Options',options)` specifies options that govern the computation of bootstrap iterations. One option requests that `bootci` perform bootstrap iterations using multiple processors, if the Parallel Computing Toolbox is available. Two options specify the random number streams to be used in bootstrap resampling. This argument is a struct that you can create with a call to `statset`. You can retrieve values of the individual fields with a call to `statget`. Applicable `statset` parameters are:

- 'UseParallel' — If 'always' and if a `matlabpool` of the Parallel Computing Toolbox is open, compute bootstrap iterations in parallel. If the Parallel Computing Toolbox is not installed, or a `matlabpool` is not open, computation occurs in serial mode. Default is 'never', or serial computation.
- UseSubstreams — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set `Streams` to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'.
- Streams — A `RandStream` object or cell array of such objects. If you do not specify `Streams`, `bootci` uses the default stream or streams. If you choose to specify `Streams`, use a single object except in the case
 - You have an open MATLAB pool
 - UseParallel is 'always'
 - UseSubstreams is 'never'In that case, use a cell array the same size as the MATLAB pool.

`[ci,bootstat] = bootci(...)` also returns the bootstrapped statistic computed for each of the `nboot` bootstrap replicate samples. Each row of `bootstat` contains the results of applying `bootfun` to one bootstrap sample. If `bootfun` returns a matrix or array, then this output is converted to a row vector for storage in `bootstat`.

Examples

Compute the confidence interval for the capability index in statistical process control:

bootci

```
y = normrnd(1,1,30,1);           % Simulated process data
LSL = -3; USL = 3;              % Process specifications
capable = @(x)(USL-LSL)./(6* std(x)); % Process capability
ci = bootci(2000,capable,y)     % BCa confidence interval
ci =
    0.8122
    1.2657

sci = bootci(2000,{capable,y},'type','student') % Studentized ci
sci =
    0.7739
    1.2707
```

See Also

[bootstrp](#) | [jackknife](#) | [statget](#) | [statset](#) | [randsample](#) | [parfor](#)

Purpose

Bootstrap sampling

Syntax

```
bootstat = bootstrap(nboot,bootfun,d1,...)
[bootstat,bootsam] = bootstrap(...)
bootstat = bootstrap(...,'Name',Value)
```

Description

`bootstat = bootstrap(nboot,bootfun,d1,...)` draws `nboot` bootstrap data samples, computes statistics on each sample using `bootfun`, and returns the results in the matrix `bootstat`. `nboot` must be a positive integer. `bootfun` is a function handle specified with `@`. Each row of `bootstat` contains the results of applying `bootfun` to one bootstrap sample. If `bootfun` returns a matrix or array, then this output is converted to a row vector for storage in `bootstat`.

The third and later input arguments (`d1,...`) are data (scalars, column vectors, or matrices) used to create inputs to `bootfun`. `bootstrap` creates each bootstrap sample by sampling with replacement from the rows of the non-scalar data arguments (these must have the same number of rows). `bootfun` accepts scalar data unchanged.

`[bootstat,bootsam] = bootstrap(...)` returns an `n`-by-`nboot` matrix of bootstrap indices, `bootsam`. Each column in `bootsam` contains indices of the values that were drawn from the original data sets to constitute the corresponding bootstrap sample. For example, if `d1,...` each contain 16 values, and `nboot = 4`, then `bootsam` is a 16-by-4 matrix. The first column contains the indices of the 16 values drawn from `d1,...`, for the first of the four bootstrap samples, the second column contains the indices for the second of the four bootstrap samples, and so on. (The bootstrap indices are the same for all input data sets.) To get the output samples `bootsam` without applying a function, set `bootfun` to empty (`[]`).

`bootstat = bootstrap(...,'Name',Value)` uses additional arguments specified by one or more `Name,Value` pair arguments. The name-value pairs must appear after the data arguments. The available name-value pairs:

- `'Weights'` — Observation weights. The `weights` value must be a vector of nonnegative numbers with at least one positive element.

The number of elements in `weights` must be equal to the number of rows in non-scalar input arguments to `bootstrap`. To obtain one bootstrap replicate, `bootstrap` samples N out of N with replacement using these weights as multinomial sampling probabilities.

- 'Options' — The value is a structure that contains options specifying whether to compute bootstrap iterations in parallel, and specifying how to use random numbers during the bootstrap sampling. Create the options structure with `statset`. Applicable `statset` parameters are:
 - 'UseParallel' — If 'always' and if a `matlabpool` of the Parallel Computing Toolbox is open, compute bootstrap iterations in parallel. If the Parallel Computing Toolbox is not installed, or a `matlabpool` is not open, computation occurs in serial mode. Default is 'never', meaning serial computation.
 - UseSubstreams — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set `Streams` to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'.
 - Streams — A `RandStream` object or cell array of such objects. If you do not specify `Streams`, `bootstrap` uses the default stream or streams. If you choose to specify `Streams`, use a single object except in the case
 - You have an open MATLAB pool
 - UseParallel is 'always'
 - UseSubstreams is 'never'In that case, use a cell array the same size as the MATLAB pool.

Examples

Bootstrapping a Correlation Coefficient Standard Error

Load a data set containing the LSAT scores and law-school GPA for 15 students. These 15 data points are resampled to create 1000 different data sets, and the correlation between the two variables is computed for each data set.

```
load lawdata
[bootstat,bootsam] = bootstrp(1000,@corr,lsat,gpa);
```

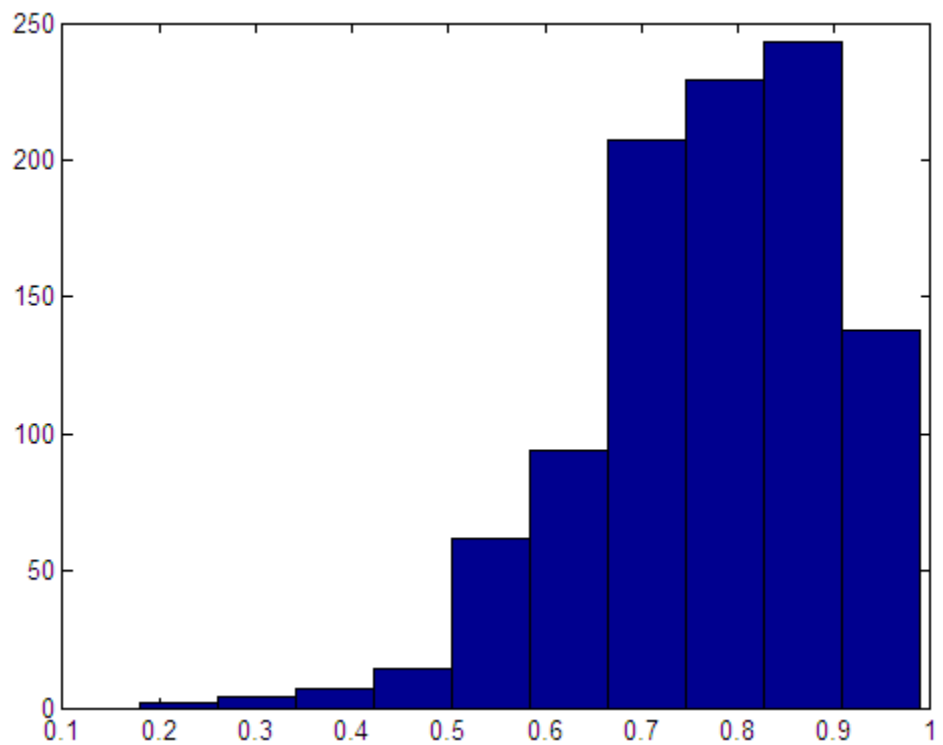
Display the first 5 bootstrapped correlation coefficients.

```
bootstat(1:5,:)
ans =
    0.6600
    0.7969
    0.5807
    0.8766
    0.9197
```

Display the indices of the data selected for the first 5 bootstrap samples.

```
bootsam(:,1:5)
ans =
     9     8    15    11    15
    14     7     6     7    14
     4     6    10     3    11
     3    10    11     9     2
    15     4    13     4    14
     9     4     5     2    10
     8     5     4     3    13
     1     9     1    15    11
    10     8     6    12     3
     1     4     5     2     8
     1     1    10     6     2
     3    10    15    10     8
    14     6    10     3     8
    13    12     1     2     4
    12     6     4     9     8
hist(bootstat)
```

bootstrap



The histogram shows the variation of the correlation coefficient across all the bootstrap samples. The sample minimum is positive, indicating that the relationship between LSAT score and GPA is not accidental.

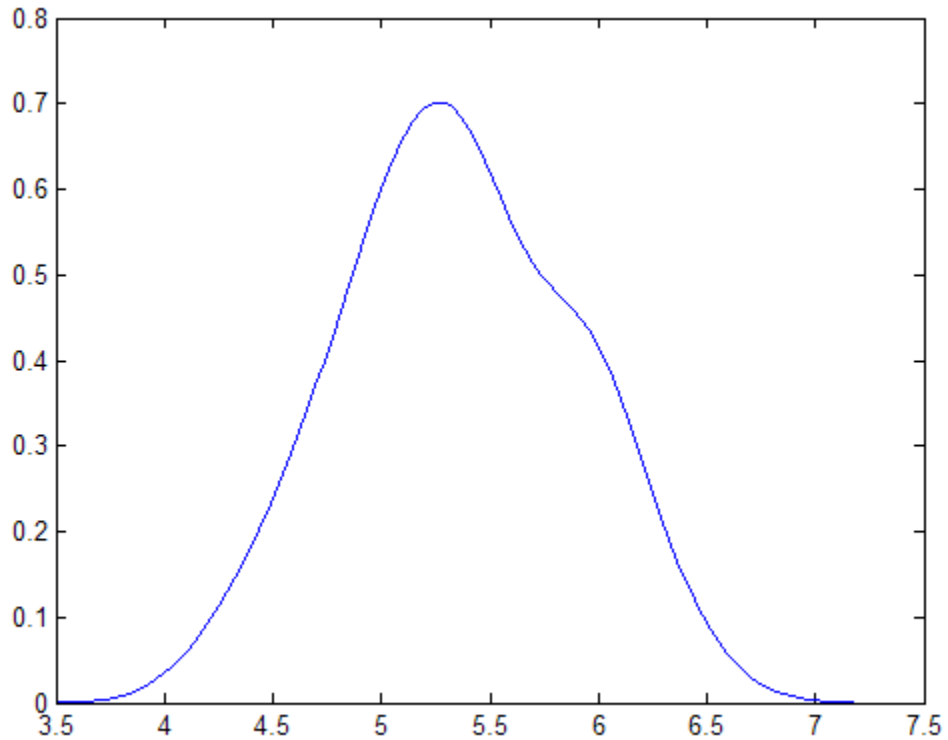
Finally, compute a bootstrap standard of error for the estimated correlation coefficient.

```
se = std(bootstat)
se =
    0.1327
```

Estimating the Density of Bootstrapped Statistic

Compute a sample of 100 bootstrapped means of random samples taken from the vector Y, and plot an estimate of the density of these bootstrapped means:

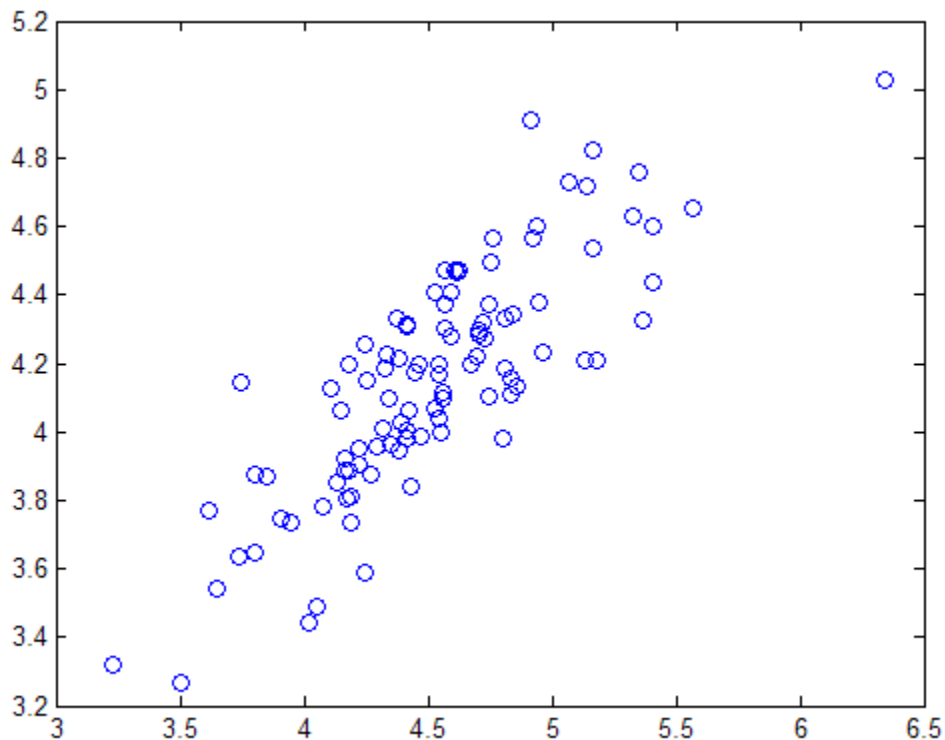
```
y = exprnd(5,100,1);  
m = bootstrap(100,@mean,y);  
[fi,xi] = ksdensity(m);  
plot(xi,fi);
```



Bootstrapping More Than One Statistic

Compute a sample of 100 bootstrapped means and standard deviations of random samples taken from the vector Y, and plot the bootstrap estimate pairs:

```
y = exprnd(5,100,1);  
stats = bootstrap(100,@(x)[mean(x) std(x)],y);  
plot(stats(:,1),stats(:,2),'o')
```



Bootstrapping a Regression Model

Estimate the standard errors for a coefficient vector in a linear regression by bootstrapping residuals:

```
load hald
x = [ones(size(heat)),ingredients];
y = heat;
b = regress(y,x);
yfit = x*b;
resid = y - yfit;
se = std(bootstrp(...
    1000,@(bootr)regress(yfit+bootr,x),resid));
```

See Also

hist | bootci | ksdensity | parfor | random | randsample |
RandStream | statget | statset

boxplot

Purpose Box plot

Syntax
`boxplot(X)`
`boxplot(X,G)`
`boxplot(axes,X,...)`
`boxplot(...,'Name',value)`

Description `boxplot(X)` produces a box plot of the data in X . If X is a matrix, there is one box per column; if X is a vector, there is just one box. On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually. For controlling how much the whiskers extend, see the 'whiskers' name-value pair argument.

`boxplot(X,G)` specifies one or more grouping variables G , producing a separate box for each set of X values sharing the same G value or values. Grouping variables must have one row per element of X , or one row per column of X . Specify a single grouping variable in G using a vector, a character array, a cell array of strings, or a vector categorical array; specify multiple grouping variables in G using a cell array of these variable types, such as `{G1 G2 G3}`, or by using a matrix. If multiple grouping variables are used, they must all be the same length. Groups that contain a NaN value or an empty string in a grouping variable are omitted, and are not counted in the number of groups considered by other parameters.

By default, character and string grouping variables are sorted in the order they initially appear in the data, categorical grouping variables are sorted by the order of their levels, and numeric grouping variables are sorted in numeric order. To control the order of groups, do one of the following:

- Use categorical variables in G and specify the order of their levels.
- Use the 'grouporder' parameter described below.
- Pre-sort your data.

`boxplot(axes,X,...)` creates the plot in the axes with handle axes.

`boxplot(..., 'Name', value)` specifies one or more optional parameter name/value pairs, as described in the following table. Specify *Name* in single quotes.

Name	Value
'plotstyle'	<ul style="list-style-type: none"> • 'traditional' — Traditional box style. This is the default. • 'compact' — Box style designed for plots with many groups. This style changes the defaults for some other parameters, as described in the following table.
'boxstyle'	<ul style="list-style-type: none"> • 'outline' — Draws an unfilled box with dashed whiskers. This is the default. • 'filled' — Draws a narrow filled box with lines for whiskers.
'colorgroup'	One or more grouping variables, of the same type as permitted for <code>G</code> , specifying that the box color should change when the specified variables change. The default is <code>[]</code> for no box color change.
'colors'	Colors for boxes, specified as a single color (such as 'r' or <code>[1 0 0]</code>) or multiple colors (such as 'rgbm' or a three-column matrix of RGB values). The sequence is replicated or truncated as required, so for example 'rb' gives boxes that alternate in color. The default when no 'colorgroup' is specified is to use the same color scheme for all boxes. The default when 'colorgroup' is specified is a modified hsv colormap.

boxplot

Name	Value
'datalim'	A two-element vector containing lower and upper limits, used by 'extrememode' to determine which points are extreme. The default is [-Inf Inf].
'extrememode'	<ul style="list-style-type: none">• 'clip' — Moves data outside the <code>datalim</code> limits to the limit. This is the default.• 'compress' — Evenly distributes data outside the <code>datalim</code> limits in a region just outside the limit, retaining the relative order of the points. <p>A dotted line marks the limit if any points are outside it, and two gray lines mark the compression region if any points are compressed. Values at +/-Inf can be clipped or compressed, but NaN values still do not appear on the plot. Box notches are drawn to scale and may extend beyond the bounds if the median is inside the limit; they are not drawn if the median is outside the limits.</p>
'factordirection'	<ul style="list-style-type: none">• 'data' — Arranges factors with the first value next to the origin. This is the default.• 'list' — Arranges factors left-to-right if on the <i>x</i> axis or top-to-bottom if on the <i>y</i> axis.• 'auto' — Uses 'data' for numeric grouping variables and 'list' for strings.

Name	Value
'fullfactors'	<ul style="list-style-type: none"> • 'off' — One group for each unique row of G. This is the default. • 'on' — Create a group for each possible combination of group variable values, including combinations that do not appear in the data.
'factorseparator'	<p>Specifies which factors should have their values separated by a grid line. The value may be 'auto' or a vector of grouping variable numbers. For example, [1 2] adds a separator line when the first or second grouping variable changes value. 'auto' is [] for one grouping variable and [1] for two or more grouping variables. The default is [].</p>
'factorgap'	<p>Specifies an extra gap to leave between boxes when the corresponding grouping factor changes value, expressed as a percentage of the width of the plot. For example, with [3 1], the gap is 3% of the width of the plot between groups with different values of the first grouping variable, and 1% between groups with the same value of the first grouping variable but different values for the second. 'auto' specifies that boxplot should choose a gap automatically. The default is [].</p>
'grouporder'	<p>Order of groups for plotting, specified as a cell array of strings. With multiple grouping variables, separate values within each string with a comma. Using categorical arrays as grouping variables is an easier way to control the order of the boxes. The default is [], which does not reorder the boxes.</p>

boxplot

Name	Value
'jitter'	Maximum distance d to displace outliers along the factor axis by a uniform random amount, in order to make duplicate points visible. A d of 1 makes the jitter regions just touch between the closest adjacent groups. The default is 0.
'labels'	<p>A character array, cell array of strings, or numeric vector of box labels. There may be one label per group or one label per X value. Multiple label variables may be specified via a numeric matrix or a cell array containing any of these types.</p> <hr/> <p>Tip To remove labels from a plot, use the following command:</p> <pre>set(gca,'XTickLabel',{' '})</pre> <hr/>
'labelorientation'	<ul style="list-style-type: none">• 'inline' — Rotates the labels to be vertical. This is the default when <code>plotstyle</code> is 'compact'.• 'horizontal' — Leaves the labels horizontal. This is the default when <code>plotstyle</code> has the default value of 'traditional'. <p>When the labels are on the y axis, both settings leave the labels horizontal.</p>

Name	Value
'labelverbosity'	<ul style="list-style-type: none"> • 'all' — Displays every label. This is the default. • 'minor' — Displays a label for a factor only when that factor has a different value from the previous group. • 'majorminor' — Displays a label for a factor when that factor or any factor major to it has a different value from the previous group.
'medianstyle'	<ul style="list-style-type: none"> • 'line' — Draws a line for the median. This is the default. • 'target' — Draws a black dot inside a white circle for the median.
'notch'	<ul style="list-style-type: none"> • 'on' — Draws comparison intervals using notches when plotstyle is 'traditional', or triangular markers when plotstyle is 'compact'. • 'marker' — Draws comparison intervals using triangular markers. • 'off' — Omits notches. This is the default. <p>Two medians are significantly different at the 5% significance level if their intervals do not overlap. Interval endpoints are the extremes of the notches or the centers of the triangular markers. The extremes correspond to $q_2 - 1.57(q_3 - q_1)/\sqrt{n}$ and $q_2 + 1.57(q_3 - q_1)/\sqrt{n}$, where q_2 is the median (50th percentile), q_1 and q_3 are the 25th and 75th percentiles, respectively, and n is the number of observations without any NaN values. When</p>

boxplot

Name	Value
	the sample size is small, notches may extend beyond the end of the box.
'orientation'	<ul style="list-style-type: none">'vertical' — Plots X on the y axis. This is the default.'horizontal' — Plots X on the x axis.
'outliersize'	Size of the marker used for outliers, in points. The default is 6 (6/72 inch).
'positions'	Box positions specified as a numeric vector with one entry per group or X value. The default is $1:\text{numGroups}$, where numGroups is the number of groups.
'symbol'	Symbol and color to use for outliers, using the same values as the <code>LineStyle</code> parameter in <code>plot</code> . The default is 'r+'. If the symbol is omitted then the outliers are invisible; if the color is omitted then the outliers have the same color as their corresponding box.
'whisker'	Maximum whisker length w . The default is a w of 1.5. Points are drawn as outliers if they are larger than $q_3 + w(q_3 - q_1)$ or smaller than $q_1 - w(q_3 - q_1)$, where q_1 and q_3 are the 25th and 75th percentiles, respectively. The default of 1.5 corresponds to approximately $\pm 2.7\sigma$ and 99.3 coverage if the data are normally distributed. The plotted whisker extends to the <i>adjacent value</i> , which is the most extreme data value that is not an outlier. Set <code>whisker</code> to 0 to give no whiskers and to make every point outside of q_1 and q_3 an outlier.
'widths'	A scalar or vector of box widths for when <code>boxstyle</code> is 'outline'. The default is half of the minimum separation between boxes,

Name	Value
	which is 0.5 when the <code>positions</code> argument takes its default value. The list of values is replicated or truncated as necessary.

When the `plotstyle` parameter takes the value `'compact'`, the following default values for other parameters apply.

Parameter	Default when <code>plotstyle</code> is <code>'compact'</code>
<code>'boxstyle'</code>	<code>'filled'</code>
<code>'factorseparator'</code>	<code>'auto'</code>
<code>'factorgap'</code>	<code>'auto'</code>
<code>'jitter'</code>	0.5
<code>'labelorientation'</code>	<code>'inline'</code>
<code>'labelverbosity'</code>	<code>'majorminor'</code>
<code>'medianstyle'</code>	<code>'target'</code>
<code>'outliersize'</code>	4
<code>'symbol'</code>	<code>'o'</code>

You can see data values and group names using the data cursor in the figure window. The cursor shows the original values of any points affected by the `datalim` parameter. You can label the group to which an outlier belongs using the `gname` function.

To modify graphics properties of a box plot component, use `findobj` with the `Tag` property to find the component's handle. `Tag` values for box plot components depend on parameter settings, and are listed in the table below.

boxplot

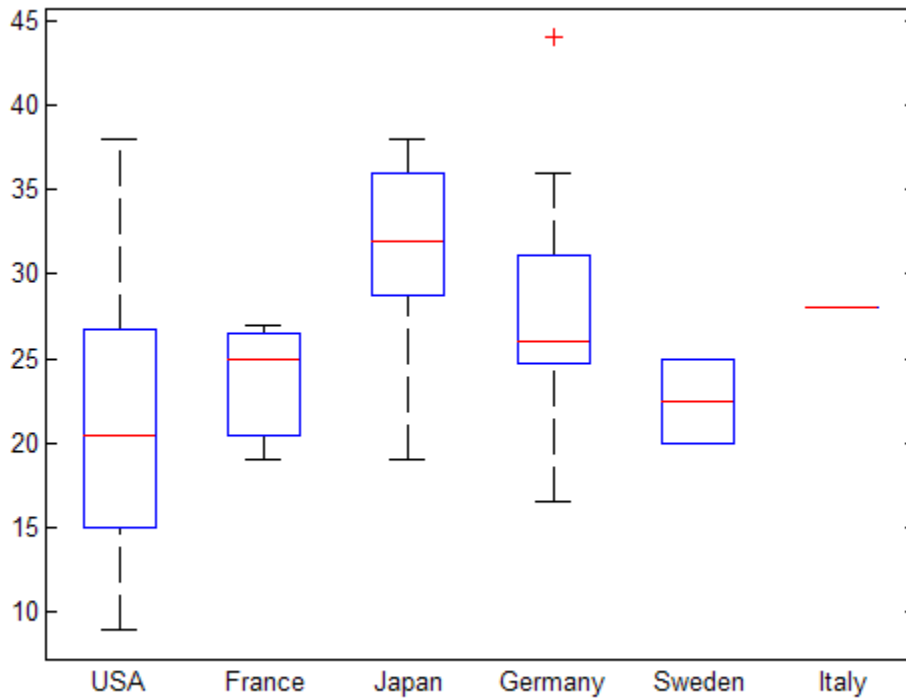
Parameter Settings	Tag Values
All settings	<ul style="list-style-type: none">• 'Box'• 'Outliers'
When 'plotstyle' is 'traditional'	<ul style="list-style-type: none">• 'Median'• 'Upper Whisker'• 'Lower Whisker'• 'Upper Adjacent Value'• 'Lower Adjacent Value'
When 'plotstyle' is 'compact'	<ul style="list-style-type: none">• 'Whisker'• 'MedianOuter'• 'MedianInner'
When 'notch' is 'marker'	<ul style="list-style-type: none">• 'NotchLo'• 'NotchHi'

Examples

Example 1

Create a box plot of car mileage, grouped by country:

```
load carsmall
boxplot(MPG,Origin)
```

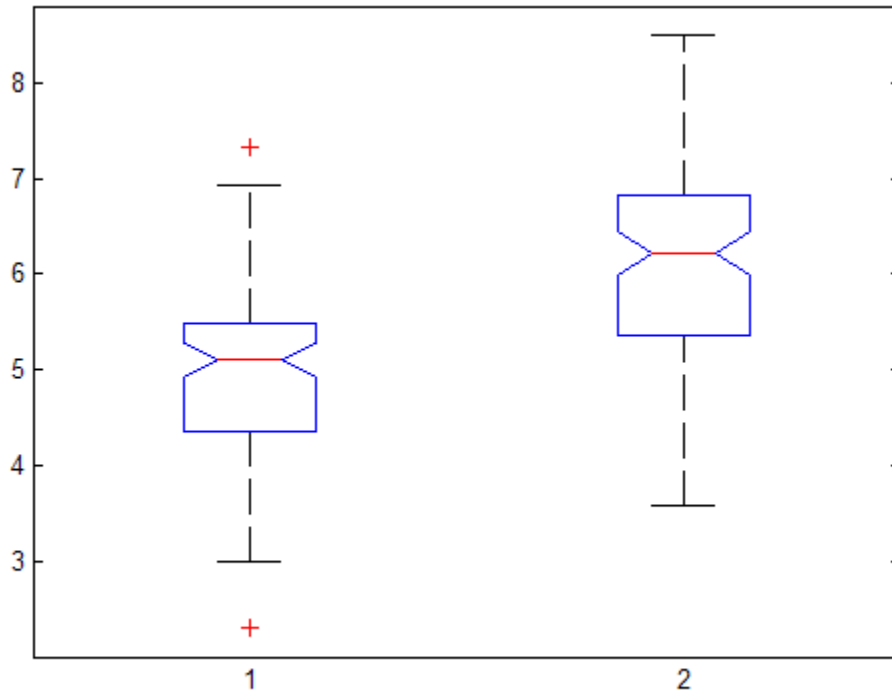



Example 2

Create notched box plots for two groups of sample data:

```
x1 = normrnd(5,1,100,1);  
x2 = normrnd(6,1,100,1);  
boxplot([x1,x2], 'notch', 'on')
```

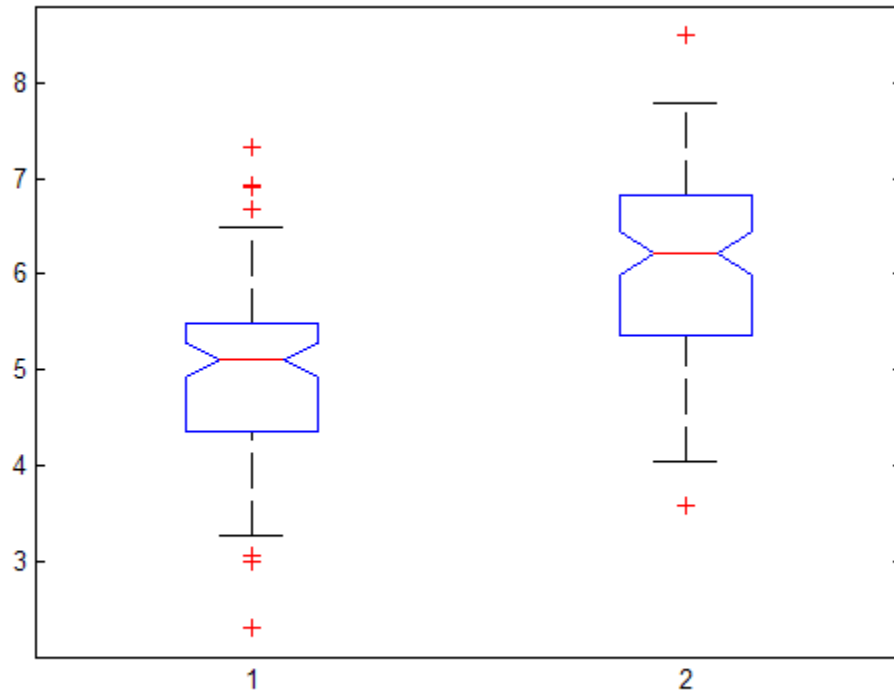
boxplot



The difference between the medians of the two groups is approximately 1. Since the notches in the box plot do not overlap, you can conclude, with 95% confidence, that the true medians do differ.

The following figure shows the box plot for the same data with the length of the whiskers specified as 1.0 times the interquartile range. Points beyond the whiskers are displayed using +.

```
boxplot([x1,x2], 'notch', 'on', 'whisker', 1)
```



Example 3

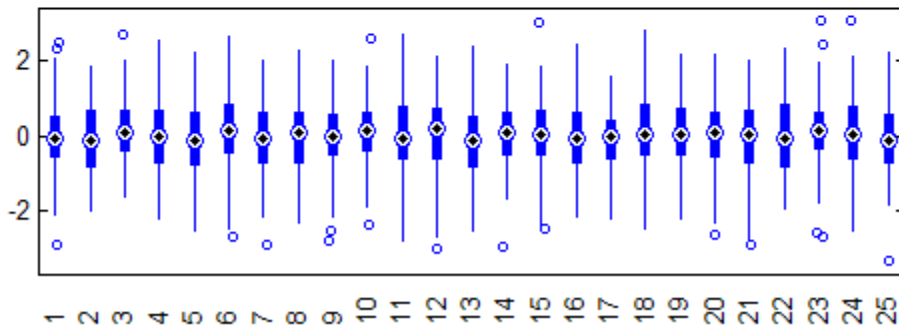
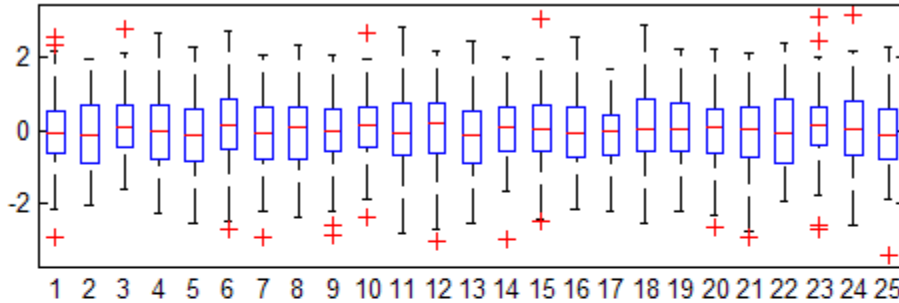
A plotstyle of 'compact' is useful for large numbers of groups:

```
X = randn(100,25);
```

```
subplot(2,1,1)  
boxplot(X)
```

```
subplot(2,1,2)  
boxplot(X, 'plotstyle', 'compact')
```

boxplot



References

- [1] McGill, R., J. W. Tukey, and W. A. Larsen. "Variations of Boxplots." *The American Statistician*. Vol. 32, No. 1, 1978, pp. 12–16.
- [2] Velleman, P.F., and D.C. Hoaglin. *Applications, Basics, and Computing of Exploratory Data Analysis*. Pacific Grove, CA: Duxbury Press, 1981.
- [3] Nelson, L. S. "Evaluating Overlapping Confidence Intervals." *Journal of Quality Technology*. Vol. 21, 1989, pp. 140–141.

See Also [anova1](#) | [axes_props](#) | [kruskalwallis](#) | [multcompare](#)

piecewisedistribution.boundary

Purpose Piecewise distribution boundaries

Syntax `[p,q] = boundary(obj)`
`[p,q] = boundary(obj,i)`

Description `[p,q] = boundary(obj)` returns the boundary points between segments of the piecewise distribution object, `obj`. `p` is a vector of cumulative probabilities at each boundary. `q` is a vector of quantiles at each boundary.

`[p,q] = boundary(obj,i)` returns `p` and `q` for the *i*th boundary.

Examples Fit Pareto tails to a *t* distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);
obj = paretotails(t,0.1,0.9);
[p,q] = boundary(obj)
p =
    0.1000
    0.9000
q =
   -1.7766
    1.8432
```

See Also `paretotails` | `cdf` | `icdf` | `nsegments`

Purpose	<i>D</i> -optimal design from candidate set using row exchanges
Syntax	<code>rlist = candexch(C,nrows)</code> <code>rlist = candexch(C,nrows,Name,Value)</code>
Description	<code>rlist = candexch(C,nrows)</code> uses a row-exchange algorithm to select a <i>D</i> -optimal design from the candidate set <i>C</i> . <code>rlist = candexch(C,nrows,Name,Value)</code> generates a <i>D</i> -optimal design with additional options specified by one or more <i>Name,Value</i> pair arguments.
Input Arguments	C N-by-P matrix containing the values of P model terms at each of N points. nrows The desired number of rows in the design. Name-Value Pair Arguments Specify optional comma-separated pairs of <i>Name,Value</i> arguments, where <i>Name</i> is the argument name and <i>Value</i> is the corresponding value. <i>Name</i> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <i>Name1,Value1,...,NameN,ValueN</i> . display When 'on', displays iteration number. Disable the display by setting to 'off'. Default: 'on', except when the <i>UseParallel</i> option is 'always' init nrows-by-P matrix giving an initial design. Default: A random subset of the rows of <i>C</i>

maxiter

Maximum number of iterations, a positive integer.

Default: 10

options

A structure that specifies whether to run in parallel, and specifies the random stream or streams. Create the `options` structure with `statset`. Option fields:

- `UseParallel` — Set to 'always' to compute in parallel. Default is 'never'.
- `UseSubstreams` — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set `Streams` to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'.
- `Streams` — A `RandStream` object or cell array of such objects. If you do not specify `Streams`, `candexch` uses the default stream or streams. If you choose to specify `Streams`, use a single object except in the case
 - You have an open MATLAB pool
 - `UseParallel` is 'always'
 - `UseSubstreams` is 'never'In that case, use a cell array the same size as the MATLAB pool.

Default: []

start

An `nobs-by-p` matrix of factor settings, specifying a set of `nobs` fixed design points to include in the design. `candexch` finds `nrows` additional rows to add to the `start` design. The parameter provides the same functionality as the `daugment` function, using a row-exchange algorithm rather than a coordinate-exchange algorithm.

Default: []

tries

Number of times to try to generate a design from a new starting point. The algorithm uses random points for each try, except possibly the first.

Default: 1

Output Arguments

rlist

Vector of length `nrows` listing the selected rows.

Examples

This example shows how to generate a D -optimal design when there is a restriction on the candidate set, so the `rowexch` function isn't appropriate.

```
F = (fullfact([5 5 5])-1)/4; % factor settings in unit cube
T = sum(F,2)<=1.51;        % find rows matching a restriction
F = F(T,:);               % take only those rows
C = [ones(size(F,1),1) F F.^2];
                           % compute model terms including
                           % a constant and all squared terms
R = candexch(C,12);       % find a D-optimal 12-point subset
X = F(R,:);               % get factor settings
```

Algorithms

`candexch` selects a starting design X at random, and uses a row-exchange algorithm to iteratively replace rows of X by rows of C in an attempt to improve the determinant of $X' * X$.

Alternatives

The `rowexch` function also generates D -optimal designs using a row-exchange algorithm, but it automatically generates a candidate set that is appropriate for a specified model. The `daugment` function augments a set of fixed design points using a coordinate-exchange algorithm; the 'start' parameter provides the same functionality using the row exchange algorithm.

candexch

See Also

candgen | rowexch | cordexch | daugment | x2fx

Tutorials

- “Specify Candidate Sets” on page 15-21

How To

- “D-Optimal Designs” on page 15-15

Purpose

Candidate set generation

Syntax

```
dC = candgen(nfactors, 'model')
[dC,C] = candgen(nfactors, 'model')
[...] = candgen(nfactors, 'model', 'Name', value)
```

Description

`dC = candgen(nfactors, 'model')` generates a candidate set `dC` of treatments appropriate for estimating the parameters in the `model` with `nfactors` factors. `dC` has `nfactors` columns and one row for each candidate treatment. `model` is one of the following strings, specified inside single quotes:

- `linear` — Constant and linear terms. This is the default.
- `interaction` — Constant, linear, and interaction terms
- `quadratic` — Constant, linear, interaction, and squared terms
- `purequadratic` — Constant, linear, and squared terms

Alternatively, `model` can be a matrix specifying polynomial terms of arbitrary order. In this case, `model` should have one column for each factor and one row for each term in the model. The entries in any row of `model` are powers for the factors in the columns. For example, if a model has factors `X1`, `X2`, and `X3`, then a row `[0 1 2]` in `model` specifies the term $(X1.^0) .* (X2.^1) .* (X3.^2)$. A row of all zeros in `model` specifies a constant term, which can be omitted.

`[dC,C] = candgen(nfactors, 'model')` also returns the design matrix `C` evaluated at the treatments in `dC`. The order of the columns of `C` for a full quadratic model with `n` terms is:

- 1 The constant term
- 2 The linear terms in order 1, 2, ..., n
- 3 The interaction terms in order (1, 2), (1, 3), ..., (1, n), (2, 3), ..., ($n-1$, n)
- 4 The squared terms in order 1, 2, ..., n

Other models use a subset of these terms, in the same order.

Pass `C` to `candexch` to generate a D -optimal design using a coordinate-exchange algorithm.

`[...]` = `candgen(nfactors, 'model', 'Name', value)` specifies one or more optional name/value pairs for the design. Valid parameters and their values are listed in the following table. Specify *Name* inside single quotes.

Name	Value
bounds	Lower and upper bounds for each factor, specified as a 2-by- <code>nfactors</code> matrix. Alternatively, this value can be a cell array containing <code>nfactors</code> elements, each element specifying the vector of allowable values for the corresponding factor.
categorical	Indices of categorical predictors.
levels	Vector of number of levels for each factor.

Note The `rowexch` function automatically generates a candidate set using `candgen`, and then creates a D -optimal design from that candidate set using `candexch`. Call `candexch` separately to specify your own candidate set to the row-exchange algorithm.

Examples

The following example uses `rowexch` to generate a five-run design for a two-factor pure quadratic model using a candidate set that is produced internally:

```
dRE1 = rowexch(2,5,'purequadratic','tries',10)
dRE1 =
    -1     1
     0     0
     1    -1
     1     0
```

```
1 1
```

The same thing can be done using candgen and candexch in sequence:

```
[dC,C] = candgen(2,'purequadratic') % Candidate set, C
```

```
dC =
```

```
-1 -1
 0 -1
 1 -1
-1  0
 0  0
 1  0
-1  1
 0  1
 1  1
```

```
C =
```

```
1 -1 -1 1 1
1  0 -1 0 1
1  1 -1 1 1
1 -1  0 1 0
1  0  0 0 0
1  1  0 1 0
1 -1  1 1 1
1  0  1 0 1
1  1  1 1 1
```

```
treatments = candexch(C,5,'tries',10) % Find D-opt subset
```

```
treatments =
```

```
2
1
7
3
4
```

```
dRE2 = dC(treatments,:) % Display design
```

```
dRE2 =
```

```
0 -1
-1 -1
-1  1
```

candgen

$$\begin{array}{cc} 1 & -1 \\ -1 & 0 \end{array}$$

See Also

candexch | rowexch

Purpose

Canonical correlation

Syntax

[A,B] = canoncorr(X,Y)
 [A,B,r] = canoncorr(X,Y)
 [A,B,r,U,V] = canoncorr(X,Y)
 [A,B,r,U,V,stats] = canoncorr(X,Y)

Description

[A,B] = canoncorr(X,Y) computes the sample canonical coefficients for the n-by-d1 and n-by-d2 data matrices X and Y. X and Y must have the same number of observations (rows) but can have different numbers of variables (columns). A and B are d1-by-d and d2-by-d matrices, where $d = \min(\text{rank}(X), \text{rank}(Y))$. The jth columns of A and B contain the canonical coefficients, i.e., the linear combination of variables making up the jth canonical variable for X and Y, respectively. Columns of A and B are scaled to make the covariance matrices of the canonical variables the identity matrix (see U and V below). If X or Y is less than full rank, canoncorr gives a warning and returns zeros in the rows of A or B corresponding to dependent columns of X or Y.

[A,B,r] = canoncorr(X,Y) also returns a 1-by-d vector containing the sample canonical correlations. The jth element of r is the correlation between the jth columns of U and V (see below).

[A,B,r,U,V] = canoncorr(X,Y) also returns the canonical variables, scores. U and V are n-by-d matrices computed as

$$U = (X - \text{repmat}(\text{mean}(X), N, 1)) * A$$

$$V = (Y - \text{repmat}(\text{mean}(Y), N, 1)) * B$$

[A,B,r,U,V,stats] = canoncorr(X,Y) also returns a structure stats containing information relating to the sequence of d null

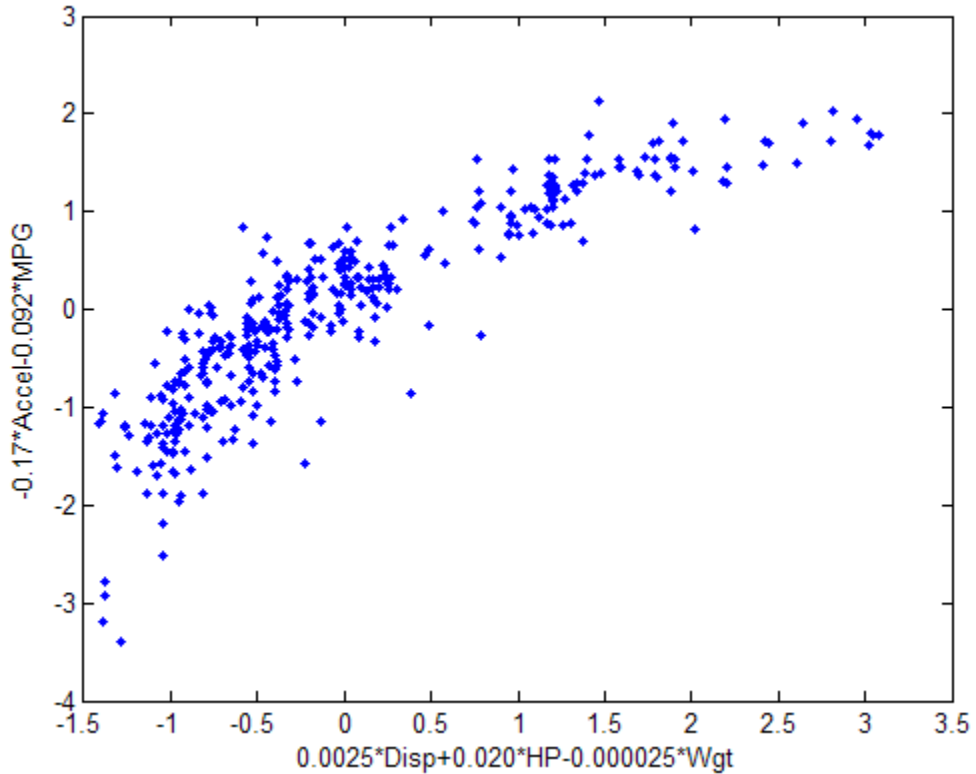
hypotheses $H_0^{(k)}$, that the (k+1)st through dth correlations are all zero, for $k = 0:(d-1)$. stats contains seven fields, each a 1-by-d vector with elements corresponding to the values of k, as described in the following table:

Field	Description
Wilks	Wilks' lambda (likelihood ratio) statistic
chisq	Bartlett's approximate chi-squared statistic for $H_0^{(k)}$ with Lawley's modification
pChisq	Right-tail significance level for chisq
F	Rao's approximate F statistic for $H_0^{(k)}$
pF	Right-tail significance level for F
df1	Degrees of freedom for the chi-squared statistic, and the numerator degrees of freedom for the F statistic
df2	Denominator degrees of freedom for the F statistic

Examples

```
load carbig;
X = [Displacement Horsepower Weight Acceleration MPG];
nans = sum(isnan(X),2) > 0;
[A B r U V] = canoncorr(X(~nans,1:3),X(~nans,4:5));

plot(U(:,1),V(:,1),'.')
xlabel('0.0025*Disp+0.020*HP-0.000025*Wgt')
ylabel('-0.17*Accel-0.092*MPG')
```

References

[1] Krzanowski, W. J. *Principles of Multivariate Analysis: A User's Perspective*. New York: Oxford University Press, 1988.

[2] Seber, G. A. F. *Multivariate Observations*. Hoboken, NJ: John Wiley & Sons, Inc., 1984.

See Also

manova1 | pca

capability

Purpose Process capability indices

Syntax `S = capability(data,specs)`

Description `S = capability(data,specs)` estimates capability indices for measurements in `data` given the specifications in `specs`. `data` can be either a vector or a matrix of measurements. If `data` is a matrix, indices are computed for the columns. `specs` can be either a two-element vector of the form `[L,U]` containing lower and upper specification limits, or (if `data` is a matrix) a two-row matrix with the same number of columns as `data`. If there is no lower bound, use `-Inf` as the first element of `specs`. If there is no upper bound, use `Inf` as the second element of `specs`.

The output `S` is a structure with the following fields:

- `mu` — Sample mean
- `sigma` — Sample standard deviation
- `P` — Estimated probability of being within limits
- `P1` — Estimated probability of being below `L`
- `Pu` — Estimated probability of being above `U`
- `Cp` — $(U-L)/(6*\text{sigma})$
- `Cp1` — $(\text{mu}-L)/(3.*\text{sigma})$
- `Cpu` — $(U-\text{mu})/(3.*\text{sigma})$
- `Cpk` — $\min(\text{Cp1},\text{Cpu})$

Indices are computed under the assumption that data values are independent samples from a normal population with constant mean and variance.

Indices divide a “specification width” (between specification limits) by a “process width” (between control limits). Higher ratios indicate a process with fewer measurements outside of specification.

Examples

Simulate a sample from a process with a mean of 3 and a standard deviation of 0.005:

```
data = normrnd(3,0.005,100,1);
```

Compute capability indices if the process has an upper specification limit of 3.01 and a lower specification limit of 2.99:

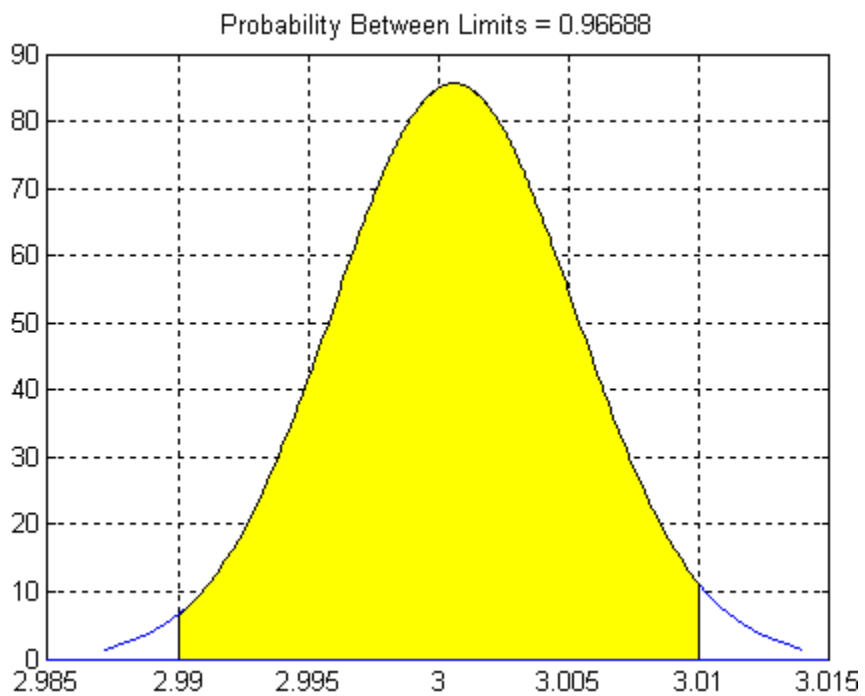
```
S = capability(data,[2.99 3.01])
```

```
S =
```

```
    mu: 3.0006
  sigma: 0.0047
     P: 0.9669
    Pl: 0.0116
    Pu: 0.0215
     Cp: 0.7156
    Cpl: 0.7567
    Cpu: 0.6744
    Cpk: 0.6744
```

Visualize the specification and process widths:

```
capaplot(data,[2.99 3.01]);
grid on
```



References

[1] Montgomery, D. *Introduction to Statistical Quality Control*. Hoboken, NJ: John Wiley & Sons, 1991, pp. 369–374.

See Also

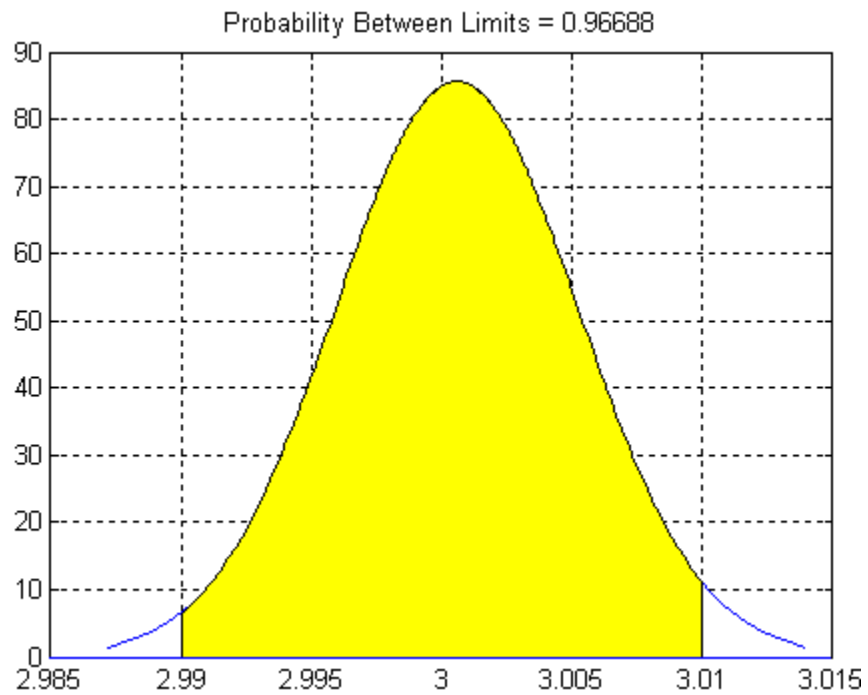
capaplot | histfit

Purpose	Process capability plot
Syntax	<pre>p = capaplot(data,specs) [p,h] = capaplot(data,specs)</pre>
Description	<p><code>p = capaplot(data,specs)</code> estimates the mean and variance for the observations in input vector <code>data</code>, and plots the pdf of the resulting T distribution. The observations in <code>data</code> are assumed to be normally distributed. The output, <code>p</code>, is the probability that a new observation from the estimated distribution will fall within the range specified by the two-element vector <code>specs</code>. The portion of the distribution between the lower and upper bounds specified in <code>specs</code> is shaded in the plot.</p> <p><code>[p,h] = capaplot(data,specs)</code> additionally returns handles to the plot elements in <code>h</code>.</p> <p><code>capaplot</code> treats NaN values in <code>data</code> as missing, and ignores them.</p>
Examples	<p>Simulate a sample from a process with a mean of 3 and a standard deviation of 0.005:</p> <pre>data = normrnd(3,0.005,100,1);</pre> <p>Compute capability indices if the process has an upper specification limit of 3.01 and a lower specification limit of 2.99:</p> <pre>S = capability(data,[2.99 3.01]) S = mu: 3.0006 sigma: 0.0047 P: 0.9669 Pl: 0.0116 Pu: 0.0215 Cp: 0.7156 Cpl: 0.7567 Cpu: 0.6744 Cpk: 0.6744</pre>

capaplot

Visualize the specification and process widths:

```
capaplot(data,[2.99 3.01]);  
grid on
```



See Also

[capability](#) | [histfit](#)

Purpose Read case names from file

Syntax `names = caseread('filename')`
`names = caseread`

Description `names = caseread('filename')` reads the contents of *filename* and returns a string matrix of names. *filename* is the name of a file in the current folder, or the complete path name of any file elsewhere. `caseread` treats each line as a separate case.

`names = caseread` displays the **Select File to Open** dialog box for interactive selection of the input file.

Examples Read the file `months.dat` created using the `casewrite` function.

```
type months.dat
```

```
January  
February  
March  
April  
May
```

```
names = caseread('months.dat')  
names =  
January  
February  
March  
April  
May
```

See Also `casewrite` | `gname` | `tdfread` | `tblread`

casewrite

Purpose Write case names to file

Syntax `casewrite(strmat, 'filename')`
`casewrite(strmat)`

Description `casewrite(strmat, 'filename')` writes the contents of string matrix `strmat` to `filename`. Each row of `strmat` represents one case name. `filename` is the name of a file in the current folder, or the complete path name of any file elsewhere. `casewrite` writes each name to a separate line in `filename`.

`casewrite(strmat)` displays the **Select File to Write** dialog box for interactive specification of the output file.

Examples

```
strmat = char('January', 'February', ...
              'March', 'April', 'May')

strmat =
January
February
March
April
May
```

```
casewrite(strmat, 'months.dat')
type months.dat
```

```
January
February
March
April
May
```

See Also `gname` | `caseread` | `tblwrite` | `tdfread`

Purpose Concatenate categorical arrays

Syntax `c = cat(dim,A,B,...)`

Description `c = cat(dim,A,B,...)` concatenates the categorical arrays `A,B,...` along dimension `dim`. All inputs must have the same size except along dimension `dim`. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs, as determined by their labels.

See Also `cat` | `horzcat` | `vertcat`

categorical

Purpose

Arrays for categorical data

Description

`categorical` is an abstract class, and you cannot create instances of it directly. You must create `nominal` or `ordinal` arrays.

Categorical arrays store data with values in a discrete set of levels. Each level is meant to capture a single, defining characteristic of an observation. If you do not encode ordering in the levels, the data and the array are `nominal`. If you do encode an ordering, the data and the array are `ordinal`.

Construction

`categorical`

Create categorical array

Methods

`addlevels`

Add levels to categorical array

`cat`

Concatenate categorical arrays

`cellstr`

Convert categorical array to cell array of strings

`char`

Convert categorical array to character array

`circshift`

Shift categorical array circularly

`ctranspose`

Transpose categorical matrix

`disp`

Display categorical array

`display`

Display categorical array

`double`

Convert categorical array to double array

`droplevels`

Drop levels

`end`

Last index in indexing expression for categorical array

<code>flipdim</code>	Flip categorical array along specified dimension
<code>fliplr</code>	Flip categorical matrix in left/right direction
<code>flipud</code>	Flip categorical matrix in up/down direction
<code>getlabels</code>	Access categorical array labels
<code>getlevels</code>	Get categorical array levels
<code>hist</code>	Plot histogram of categorical data
<code>horzcat</code>	Horizontal concatenation for categorical arrays
<code>int16</code>	Convert categorical array to signed 16-bit integer array
<code>int32</code>	Convert categorical array to signed 32-bit integer array
<code>int64</code>	Convert categorical array to signed 64-bit integer array
<code>int8</code>	Convert categorical array to signed 8-bit integer array
<code>intersect</code>	Set intersection for categorical arrays
<code>ipermute</code>	Inverse permute dimensions of categorical array
<code>isempty</code>	True for empty categorical array
<code>isequal</code>	True if categorical arrays are equal
<code>islevel</code>	Test for levels
<code>ismember</code>	True for elements of categorical array in set

categorical

<code>isscalar</code>	True if categorical array is scalar
<code>isundefined</code>	Test for undefined elements
<code>isvector</code>	True if categorical array is vector
<code>length</code>	Length of categorical array
<code>levelcounts</code>	Element counts by level
<code>ndims</code>	Number of dimensions of categorical array
<code>numel</code>	Number of elements in categorical array
<code>permute</code>	Permute dimensions of categorical array
<code>reorderlevels</code>	Reorder levels
<code>repmat</code>	Replicate and tile categorical array
<code>reshape</code>	Resize categorical array
<code>rot90</code>	Rotate categorical matrix 90 degrees
<code>setdiff</code>	Set difference for categorical arrays
<code>setlabels</code>	Label levels
<code>setxor</code>	Set exclusive-or for categorical arrays
<code>shiftdim</code>	Shift dimensions of categorical array
<code>single</code>	Convert categorical array to single array
<code>size</code>	Size of categorical array

<code>squeeze</code>	Squeeze singleton dimensions from categorical array
<code>subsasgn</code>	Subscripted assignment for categorical array
<code>subsindex</code>	Subscript index for categorical array
<code>subsref</code>	Subscripted reference for categorical array
<code>summary</code>	Summary statistics for categorical array
<code>times</code>	Product of categorical arrays
<code>transpose</code>	Transpose categorical matrix
<code>uint16</code>	Convert categorical array to unsigned 16-bit integers
<code>uint32</code>	Convert categorical array to unsigned 32-bit integers
<code>uint64</code>	Convert categorical array to unsigned 64-bit integers
<code>uint8</code>	Convert categorical array to unsigned 8-bit integers
<code>union</code>	Set union for categorical arrays
<code>unique</code>	Unique values in categorical array
<code>vertcat</code>	Vertical concatenation for categorical arrays

Properties

<code>labels</code>	Text labels for levels
<code>undeflabel</code>	Text label for undefined levels

categorical

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

How To

- “Categorical Arrays” on page 2-14

Purpose Create categorical array

Description `categorical` is an abstract class, and you cannot create instances of it directly. You must create `nominal` or `ordinal` arrays.

See Also `nominal` | `ordinal`

dataset.cat

Purpose Concatenate dataset arrays

Syntax `ds = cat(dim, ds1, ds2, ...)`

Description `ds = cat(dim, ds1, ds2, ...)` concatenates the dataset arrays `ds1`, `ds2`, ... along dimension `dim` by calling the `dataset/horzcat` or `dataset/vertcat` method. `dim` must be 1 or 2.

See Also `horzcat` | `vertcat`

Purpose	Categorical splits used for branches in decision tree
Syntax	<code>v=catsplit(t)</code> <code>v=catsplit(t,j)</code>
Description	<p><code>v=catsplit(t)</code> returns an n-by-2 cell array <code>v</code>. Each row in <code>v</code> gives left and right values for a categorical split. For each branch node <code>j</code> based on a categorical predictor variable <code>z</code>, the left child is chosen if <code>z</code> is in <code>v(j,1)</code> and the right child is chosen if <code>z</code> is in <code>v(j,2)</code>. The splits are in the same order as nodes of the tree. Nodes for these splits can be found by running <code>cuttype</code> and selecting 'categorical' cuts from top to bottom.</p> <p><code>v=catsplit(t,j)</code> takes an array <code>j</code> of rows and returns the splits for the specified rows.</p>
See Also	<code>classregtree</code>

gmdistribution.cdf

Purpose Cumulative distribution function for Gaussian mixture distribution

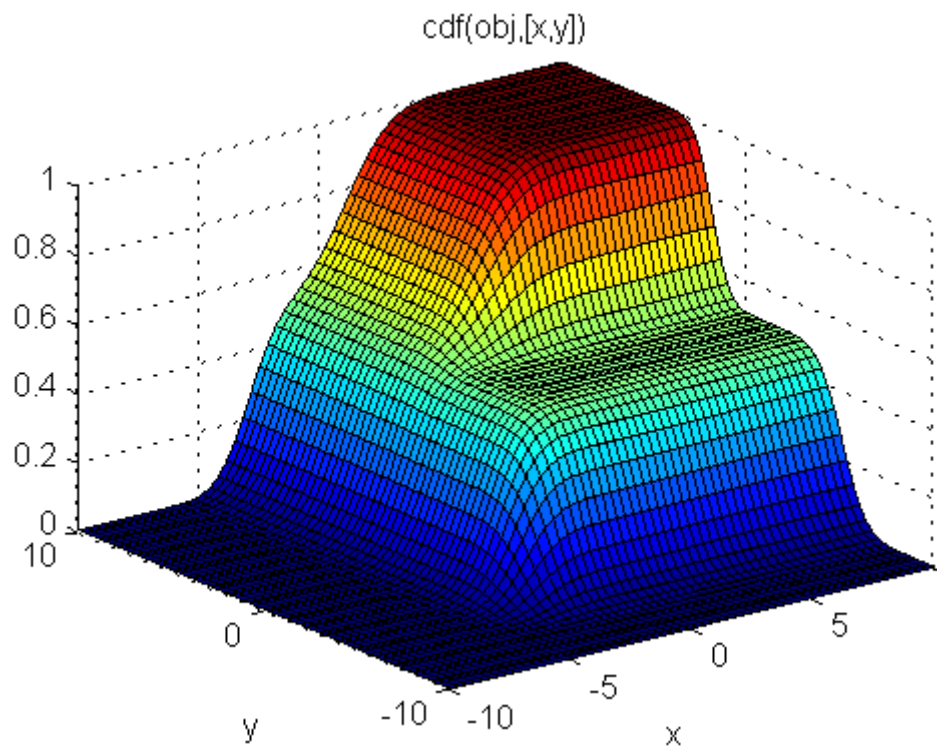
Syntax `y = cdf(obj,X)`

Description `y = cdf(obj,X)` returns a vector `y` of length n containing the values of the cumulative distribution function (`cdf`) for the `gmdistribution` object `obj`, evaluated at the n -by- d data matrix `X`, where n is the number of observations and d is the dimension of the data. `obj` is an object created by `gmdistribution` or `fit`. `y(I)` is the cdf of observation `I`.

Examples Create a `gmdistribution` object defining a two-component mixture of bivariate Gaussian distributions:

```
MU = [1 2; -3 -5];
SIGMA = cat(3,[2 0; 0 .5],[1 0; 0 1]);
p = ones(1,2)/2;
obj = gmdistribution(MU,SIGMA,p);

ezsurf(@(x,y)cdf(obj,[x y]),[-10 10],[-10 10])
```



See Also

[gmdistribution](#) | [fit](#) | [pdf](#) | [mvncdf](#)

ccdesign

Purpose Central composite design

Syntax

```
dCC = ccdesign(n)
[dCC,blocks] = ccdesign(n)
[...] = ccdesign(n,'Name',value)
```

Description `dCC = ccdesign(n)` generates a central composite design for n factors. n must be an integer 2 or larger. The output matrix `dCC` is m -by- n , where m is the number of runs in the design. Each row represents one run, with settings for all factors represented in the columns. Factor values are normalized so that the cube points take values between -1 and 1.

`[dCC,blocks] = ccdesign(n)` requests a blocked design. The output `blocks` is an m -by-1 vector of block numbers for each run. Blocks indicate runs that are to be measured under similar conditions to minimize the effect of inter-block differences on the parameter estimates.

`[...] = ccdesign(n,'Name',value)` specifies one or more optional name/value pairs for the design. Valid parameters and their values are listed in the following table. Specify *Name* in single quotes.

Parameter	Description	Values	Value Description
center	Number of center points.	Integer	Number of center points to include.
		'uniform'	Select number of center points to give uniform precision.
		'orthogonal'	Select number of center points to give an orthogonal design. This is the default.

Parameter	Description	Values	Value Description
fraction	Fraction of full-factorial cube, expressed as an exponent of 1/2.	0	Whole design. Default when $n \leq 4$.
		1	1/2 fraction. Default when $4 < n \leq 7$ or $n > 11$.
		2	1/4 fraction. Default when $7 < n \leq 9$.
		3	1/8 fraction. Default when $n = 10$.
		4	1/16 fraction. Default when $n = 11$.
type	Type of CCD.	'circumscribed'	Circumscribed (CCC). This is the default.
		'inscribed'	Inscribed (CCI).
		'faced'	Faced (CCF).
blocksize	Maximum number of points per block.	Integer	The default is Inf.

Examples

The following creates a 2-factor CCC:

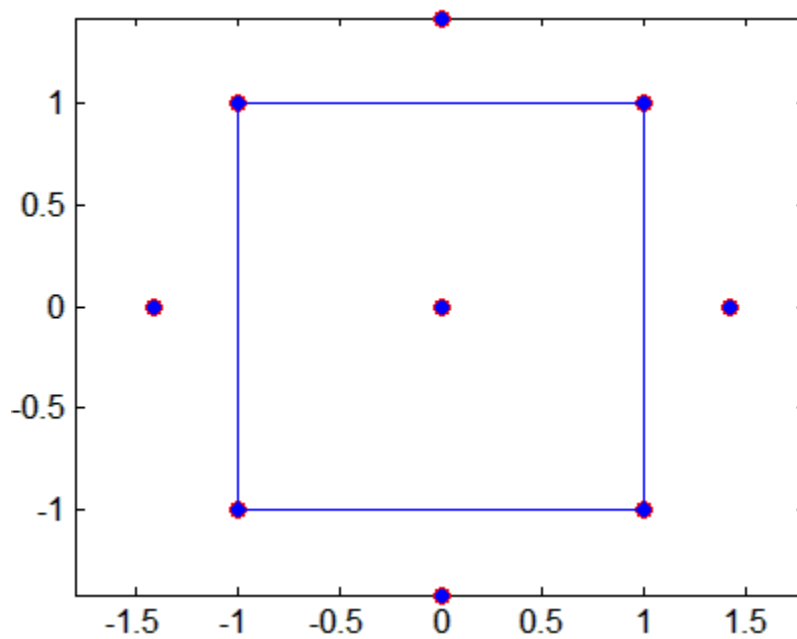
```
dCC = ccdesign(2,'type','circumscribed')
dCC =
    -1.0000    -1.0000
```

```
-1.0000    1.0000
 1.0000   -1.0000
 1.0000    1.0000
-1.4142     0
 1.4142     0
     0   -1.4142
     0    1.4142
     0     0
     0     0
     0     0
     0     0
     0     0
     0     0
     0     0
     0     0
     0     0
     0     0
```

The center point is run 8 times to reduce the correlations among the coefficient estimates.

Visualize the design as follows:

```
plot(dCC(:,1),dCC(:,2),'ro','MarkerFaceColor','b')
X = [1 -1 -1 -1; 1 1 1 -1];
Y = [-1 -1 1 -1; 1 -1 1 1];
line(X,Y,'Color','b')
axis square equal
```



See Also

`bbdesign`

Purpose Cumulative distribution functions

Syntax
`Y = cdf('name',X,A)`
`Y = cdf('name',X,A,B)`
`Y = cdf('name',X,A,B,C)`

Description `Y = cdf('name',X,A)` computes the cumulative distribution function for the one-parameter family of distributions specified by `name`. `A` contains parameter values for the distribution. The cumulative distribution function is evaluated at the values in `X` and its values are returned in `Y`.

If `X` and `A` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A`. If `A` is a scalar, it is expanded to a constant matrix the same size as `X`.

`Y` is the common size of `X` and `A` after any necessary scalar expansion.

`Y = cdf('name',X,A,B)` computes the cumulative distribution function for two-parameter families of distributions, where parameter values are given in `A` and `B`.

If `X`, `A`, and `B` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A` and `B`. If either `A` or `B` are scalars, they are expanded to constant matrices the same size as `X`.

`Y` is the common size of `X`, `A`, and `B` after any necessary scalar expansion.

`Y = cdf('name',X,A,B,C)` computes the cumulative distribution function for three-parameter families of distributions, where parameter values are given in `A`, `B`, and `C`.

If `X`, `A`, `B`, and `C` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A`, `B`, and `C`. If any of `A`, `B` or `C` are scalars, they are expanded to constant matrices the same size as `X`.

`Y` is the common size of `X`, `A`, `B`, and `C` after any necessary scalar expansion.

Acceptable strings for `name` (specified in single quotes) are:

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'beta' or 'Beta'	“Beta Distribution” on page B-4	a	b	—
'bino' or 'Binomial'	“Binomial Distribution” on page B-7	n: number of trials	p: probability of success for each trial	—
'birnbaumsaunders' or 'Birnbaum-Saunders'	“Birnbaum-Saunders Distribution” on page B-10	β	γ	—
'burr' or 'Burr'	“Burr Type XII Distribution” on page B-12	a: scale parameter	c: shape parameter	k: shape parameter
'chi2' or 'Chisquare'	“Chi-Square Distribution” on page B-25	ν : degrees of freedom	—	—
'exp' or 'Exponential'	“Exponential Distribution” on page B-29	μ : mean	—	—
'ev' or 'Extreme Value'	“Extreme Value Distribution” on page B-32	μ : location parameter	σ : scale parameter	—
'f' or 'F'	“F Distribution” on page B-38	ν_1 : numerator degrees of freedom	ν_2 : denominator degrees of freedom	—
'gam' or 'Gamma'	“Gamma Distribution” on page B-40	a: shape parameter	b: scale parameter	—
'gev' or 'Generalized Extreme Value'	“Generalized Extreme Value Distribution” on page B-45	k: shape parameter	σ : scale parameter	μ : location parameter

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'gp' or 'Generalized Pareto'	“Generalized Pareto Distribution” on page B-50	k : tail index (shape) parameter	σ : scale parameter	μ : threshold (location) parameter
'geo' or 'Geometric'	“Geometric Distribution” on page B-54	p : probability parameter	—	—
'hyge' or 'Hypergeometric'	“Hypergeometric Distribution” on page B-56	M : size of the population	K : number of items with the desired characteristic in the population	n : number of samples drawn
'inversegaussian'	“Inverse Gaussian Distribution” on page B-58	μ	λ	—
'logistic'	“Logistic Distribution” on page B-62	μ	σ	—
'loglogistic'	“Loglogistic Distribution” on page B-63	μ	σ	—
'logn' or 'Lognormal'	“Lognormal Distribution” on page B-64	μ	σ	—
'nakagami'	“Nakagami Distribution” on page B-83	μ	ω	—
'nbin' or 'Negative Binomial'	“Negative Binomial Distribution” on page B-85	r : number of successes	p : probability of success in a single trial	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'ncf' or 'Noncentral F'	“Noncentral F Distribution” on page B-91	ν_1 : numerator degrees of freedom	ν_2 : denominator degrees of freedom	δ : noncentrality parameter
'nct' or 'Noncentral t'	“Noncentral t Distribution” on page B-93	ν : degrees of freedom	δ : noncentrality parameter	—
'ncx2' or 'Noncentral Chi-square'	“Noncentral Chi-Square Distribution” on page B-89	ν : degrees of freedom	δ : noncentrality parameter	—
'norm' or 'Normal'	“Normal Distribution” on page B-96	μ : mean	σ : standard deviation	—
'poiss' or 'Poisson'	“Poisson Distribution” on page B-102	λ : mean	—	—
'rayl' or 'Rayleigh'	“Rayleigh Distribution” on page B-104	b : scale parameter	—	—
'rician'	“Rician Distribution” on page B-106	s : noncentrality parameter	σ : scale parameter	—
't' or 'T'	“Student’s t Distribution” on page B-108	ν : degrees of freedom	—	—
'tlocationscale'	“t Location-Scale Distribution” on page B-110	μ : location parameter	σ : scale parameter	ν : shape parameter
'unif' or 'Uniform'	“Uniform Distribution (Continuous)” on page B-112	a : lower endpoint (minimum)	b : upper endpoint (maximum)	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'unid' or 'Discrete Uniform'	“Uniform Distribution (Discrete)” on page B-114	N: maximum observable value	—	—
'wbl' or 'Weibull'	“Weibull Distribution” on page B-116	a: scale parameter	b: shape parameter	—

Examples

Compute the cdf of the normal distribution with mean 0 and standard deviation 1 at inputs $-2, -1, 0, 1, 2$:

```
p1 = cdf('Normal', -2:2, 0, 1)
p1 =
    0.0228    0.1587    0.5000    0.8413    0.9772
```

The order of the parameters is the same as for `normcdf`.

Compute the cdfs of Poisson distributions with rate parameters 0, 1, ..., 4 at inputs 1, 2, ..., 5, respectively:

```
p2 = cdf('Poisson', 0:4, 1:5)
p2 =
    0.3679    0.4060    0.4232    0.4335    0.4405
```

The order of the parameters is the same as for `poisscdf`.

See Also

`pdf` | `icdf`

Purpose	Cumulative distribution function for piecewise distribution
Syntax	<code>P = cdf(obj,X)</code>
Description	<code>P = cdf(obj,X)</code> returns an array <code>P</code> of values of the cumulative distribution function for the piecewise distribution object <code>obj</code> , evaluated at the values in the array <code>X</code> .
Examples	<p>Fit Pareto tails to a t distribution at cumulative probabilities 0.1 and 0.9:</p> <pre>t = trnd(3,100,1); obj = paretotails(t,0.1,0.9); [p,q] = boundary(obj) p = 0.1000 0.9000 q = -1.7766 1.8432 cdf(obj,q) ans = 0.1000 0.9000</pre>
See Also	<code>paretotails</code> <code>pdf</code> <code>icdf</code>

ProbDist.cdf

Purpose	Return cumulative distribution function (CDF) for ProbDist object	
Syntax	$Y = \text{cdf}(PD, X)$	
Description	$Y = \text{cdf}(PD, X)$ returns Y , an array containing the cumulative distribution function (CDF) for the ProbDist object PD , evaluated at values in X .	
Input Arguments	PD	An object of the class ProbDistUnivParam or ProbDistUnivKernel.
	X	A numeric array of values where you want to evaluate the CDF.
Output Arguments	Y	An array containing the cumulative distribution function (CDF) for the ProbDist object PD .
See Also	cdf	

Purpose Empirical cumulative distribution function plot

Syntax

```
cdfplot(X)
h = cdfplot(X)
[h,stats] = cdfplot(X)
```

Description `cdfplot(X)` displays a plot of the empirical cumulative distribution function (cdf) for the data in the vector `X`. The empirical cdf $F(x)$ is defined as the proportion of `X` values less than or equal to x .

This plot, like those produced by `hist` and `normplot`, is useful for examining the distribution of a sample of data. You can overlay a theoretical cdf on the same plot to compare the empirical distribution of the sample to the theoretical distribution.

The `kstest`, `kstest2`, and `lillietest` functions compute test statistics that are derived from the empirical cdf. You may find the empirical cdf plot produced by `cdfplot` useful in helping you to understand the output from those functions.

`h = cdfplot(X)` returns a handle to the cdf curve.

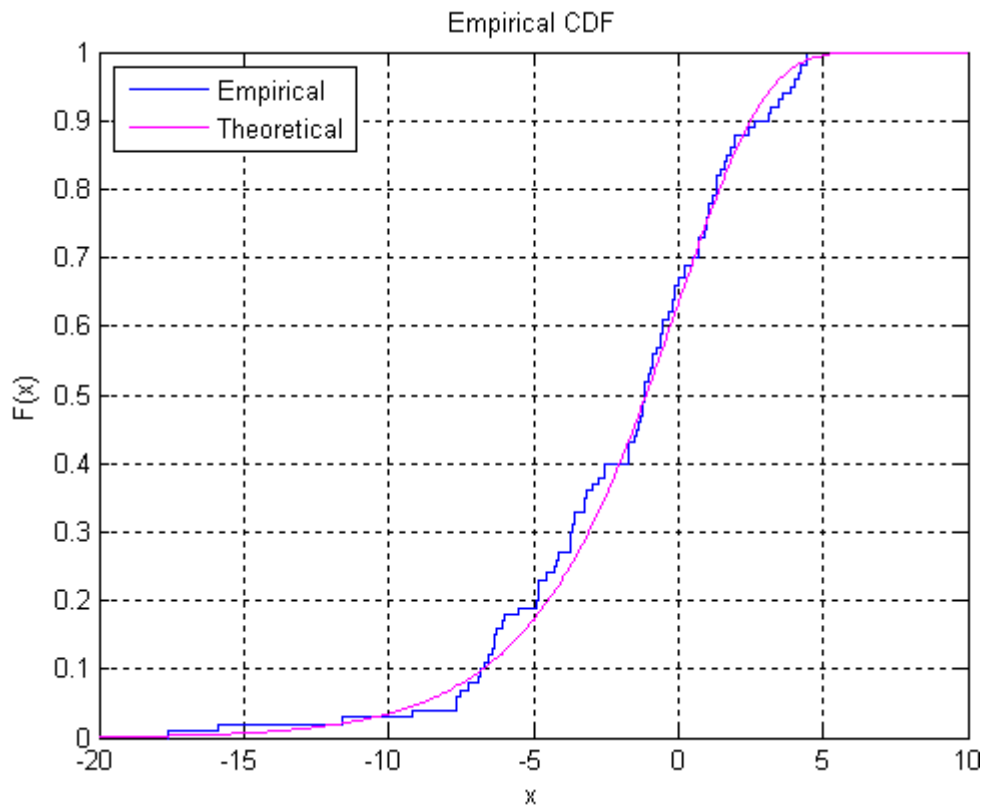
`[h,stats] = cdfplot(X)` also returns a `stats` structure with the following fields.

Field	Description
<code>stats.min</code>	Minimum value
<code>stats.max</code>	Maximum value
<code>stats.mean</code>	Sample mean
<code>stats.median</code>	Sample median (50th percentile)
<code>stats.std</code>	Sample standard deviation

Examples The following example compares the empirical cdf for a sample from an extreme value distribution with a plot of the cdf for the sampling distribution. In practice, the sampling distribution would be unknown, and would be chosen to match the empirical cdf.

cdfplot

```
y = evrnd(0,3,100,1);  
cdfplot(y)  
hold on  
x = -20:0.1:10;  
f = evcdf(x,0,3);  
plot(x,f,'m')  
legend('Empirical','Theoretical','Location','NW')
```



See Also [ecdf](#)

Purpose	Convert cell array to dataset array
Syntax	<pre>ds = cell2dataset(C) ds = cell2dataset(C,Name,Value)</pre>
Description	<p><code>ds = cell2dataset(C)</code> converts a cell array to a dataset array.</p> <p><code>ds = cell2dataset(C,Name,Value)</code> performs the conversion using additional options specified by one or more <code>Name,Value</code> pair arguments.</p>
Input Arguments	<p>C - Input cell array cell array</p> <p>Input cell array to convert to a dataset array, specified as an M-by-N cell array. Each column of <code>C</code> becomes a variable in the output dataset array, <code>ds</code>. By default, <code>cell2dataset</code> assumes that the first row of <code>C</code> contains variable names.</p> <p>Data Types cell</p> <p>Name-Value Pair Arguments</p> <p>Specify optional comma-separated pairs of <code>Name,Value</code> arguments, where <code>Name</code> is the argument name and <code>Value</code> is the corresponding value. <code>Name</code> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <code>Name1,Value1,...,NameN,ValueN</code>.</p> <p>Example: <code>'ReadVarNames',false,'ReadObsNames',true</code> specifies that the first row of the cell array does not contain variable names, but the first column contains observation names.</p> <p>ReadVarNames - Indicator for whether or not to read variable names true (default) false</p>

Indicator for whether or not to read variable names from the first row of the input cell array, specified as the comma-separated pair consisting of 'ReadVarNames' and either true or false. The default value is true, unless variable names are specified using the name-value pair argument VarNames. When ReadVarNames is false, cell2dataset creates default variable names if you do not provide any.

Example: 'ReadVarNames',false

VarNames - Variable names for output dataset array

cell array of strings

Variable names for the output dataset array, specified as the comma-separated pair consisting of 'VarNames' and a cell array of strings. You must provide a variable name for each variable in ds. The names must be valid MATLAB identifiers, and must be unique.

Example: 'VarNames', {'myVar1', 'myVar2', 'myVar3'}

ReadObsNames - Indicator for whether or not to read observation names

false (default) | true

Indicator for whether or not to read observation names from the input cell array, specified as the comma-separated pair consisting of 'ReadObsNames' and either true or false. When ReadObsNames has the value true, cell2dataset creates observation names in ds using the first column of C, and sets ds.Properties.DimNames equal to {C{1,1}, 'Variables'}.

Example: 'ReadObsNames',true

ObsNames - Observation names for output dataset array

cell array of strings

Observation names for the output dataset array, specified as the comma-separated pair consisting of 'ObsNames' and a cell array of strings. The names do not need to be valid MATLAB identifiers, but they must be unique.

NumCols - Number of columns for each variable

vector of nonnegative integers

Number of columns for each variable in `ds`, specified as the comma-separated pair consisting of `'NumCols'` and a vector of nonnegative integers. When the number of columns for a variable is greater than one, `cell2dataset` combines multiple columns in `C` into a single variable in `ds`. The vector you assign to `NumCols` must sum to `size(C,2)`, or `size(C,1)` if `ReadObsNames` is equal to `true`.

For example, to convert a cell array with eight columns into a dataset array with five variables, specify a vector with five elements that sum to eight, such as `'NumCols',[1,1,3,1,2]`.

Output Arguments**ds - Output dataset array**

dataset array

Output dataset array, returned by default with a variable for each column of `C`, an observation for each row of `C` (except for the first row), and variable names corresponding to the first row of `C`.

- If you set `ReadVarNames` equal to `false` (or specify `VarNames`), then there is an observation in `ds` for each row of `C`, and `cell2dataset` creates default variable names (or uses the names in `VarNames`).
- If you set `ReadObsNames` equal to `true`, then `cell2dataset` uses the first column of `C` as observation names.
- If you specify `NumCols`, then the number of variables in `ds` is equal to the length of the specified vector of column numbers.

Examples**Convert Cell Array to Dataset Array**

Convert a cell array to a dataset array using the default options.

Create a cell array to convert.

```
C = {'Name', 'Gender', 'SystolicBP', 'DiastolicBP';
     'CLARK', 'M', 124, 93;
     'BROWN', 'F', 122, 80;
     'MARTIN', 'M', 130, 92}
```

cell2dataset

```
C =  
  
      'Name'      'Gender'      'SystolicBP'      'DiastolicBP'  
      'CLARK'     'M'           [      124]      [      93]  
      'BROWN'     'F'           [      122]      [      80]  
      'MARTIN'    'M'           [      130]      [      92]
```

Convert the cell array to a dataset array.

```
ds = cell2dataset(C)
```

```
ds =  
  
      Name          Gender      SystolicBP      DiastolicBP  
      'CLARK'      'M'           124             93  
      'BROWN'      'F'           122             80  
      'MARTIN'     'M'           130             92
```

The first row of `C` become the variable names in the output dataset array, `ds`.

Create a Dataset Array with Multicolumn Variables

Convert a cell array to a dataset array containing multicolumn variables.

Create a cell array to convert.

```
C = {'Name', 'Gender', 'SystolicBP', 'DiastolicBP';  
     'CLARK', 'M', 124, 93;  
     'BROWN', 'F', 122, 80;  
     'MARTIN', 'M', 130, 92}
```

```
C =  
  
      'Name'      'Gender'      'SystolicBP'      'DiastolicBP'  
      'CLARK'     'M'           [      124]      [      93]  
      'BROWN'     'F'           [      122]      [      80]  
      'MARTIN'    'M'           [      130]      [      92]
```

Convert the cell array to a dataset array, combining the systolic and diastolic blood pressure measurements into one variable named `BloodPressure`.

```
ds = cell2dataset(C,'NumCols',[1,1,2]);  
ds.Properties.VarNames{3} = 'BloodPressure';  
ds
```

```
ds =
```

Name	Gender	BloodPressure
'CLARK'	'M'	124 93
'BROWN'	'F'	122 80
'MARTIN'	'M'	130 92

The output dataset array has three observations and three variables.

```
size(ds)
```

```
ans =
```

```
3 3
```

See Also

[dataset](#) | [dataset2cell](#) | [struct2dataset](#)

Related Examples

- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Create a Dataset Array from a File” on page 2-92

Concepts

- “Dataset Arrays” on page 2-156

categorical.cellstr

Purpose Convert categorical array to cell array of strings

Syntax `B = cellstr(A)`

Description `B = cellstr(A)` converts the categorical array `A` to a cell array of strings. Each element of `B` contains the categorical level label for the corresponding element of `A`.

See Also `char` | `getlabels`

Purpose Create cell array of strings from dataset array

Syntax
B = cellstr(A)
B = cellstr(A, VARS)

Description
B = cellstr(A) returns the contents of the dataset A, converted to a cell array of strings. The variables in the dataset must support the conversion and must have compatible sizes.
B = cellstr(A, VARS) returns the contents of the dataset variables specified by VARS. VARS is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector.

See Also dataset.double | dataset.replacdata

categorical.char

Purpose Convert categorical array to character array

Syntax `B = char(A)`

Description `B = char(A)` converts the categorical array `A` to a 2-D character matrix. `char` does not preserve the shape of `A`. `B` contains `numel(A)` rows, and each row of `B` contains the categorical level label for the corresponding element of `A(:)`.

See Also `cellstr` | `getlabels`

Purpose Chi-square cumulative distribution function

Syntax `P = chi2cdf(X,V)`

Description `P = chi2cdf(X,V)` computes the chi-square cdf at each of the values in `X` using the corresponding degrees of freedom in `V`. `X` and `V` can be vectors, matrices, or multidimensional arrays that have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input.

The degrees of freedom parameters in `V` must be positive integers, and the values in `X` must lie on the interval `[0 Inf]`.

The χ^2 cdf for a given value x and degrees-of-freedom ν is

$$p = F(x | \nu) = \int_0^x \frac{t^{(\nu-2)/2} e^{-t/2}}{2^{\nu/2} \Gamma(\nu/2)} dt$$

where $\Gamma(\cdot)$ is the Gamma function.

The chi-square density function with ν degrees-of-freedom is the same as the gamma density function with parameters $\nu/2$ and 2.

Examples

```
probability = chi2cdf(5,1:5)
probability =
    0.9747    0.9179    0.8282    0.7127    0.5841
```

```
probability = chi2cdf(1:5,1:5)
probability =
    0.6827    0.6321    0.6084    0.5940    0.5841
```

See Also `cdf` | `chi2pdf` | `chi2inv` | `chi2stat` | `chi2rnd`

How To • “Chi-Square Distribution” on page B-25

chi2gof

Purpose Chi-square goodness-of-fit test

Syntax

```
h = chi2gof(x)
[h,p] = chi2gof(...)
[h,p,stats] = chi2gof(...)
[...] = chi2gof(X,'Name',value)
```

Description `h = chi2gof(x)` performs a chi-square goodness-of-fit test of the default null hypothesis that the data in vector `x` are a random sample from a normal distribution with mean and variance estimated from `x`, against the alternative that the data are not normally distributed with the estimated mean and variance. The result `h` is 1 if the null hypothesis can be rejected at the 5% significance level. The result `h` is 0 if the null hypothesis cannot be rejected at the 5% significance level.

The null distribution can be changed from a normal distribution to an arbitrary discrete or continuous distribution. See the syntax for specifying optional argument `name/value` pairs below.

The test is performed by grouping the data into bins, calculating the observed and expected counts for those bins, and computing the chi-square test statistic

$$\chi^2 = \sum_{i=1}^N (O_i - E_i)^2 / E_i$$

where O_i are the observed counts and E_i are the expected counts. The statistic has an approximate chi-square distribution when the counts are sufficiently large. Bins in either tail with an expected count less than 5 are pooled with neighboring bins until the count in each extreme bin is at least 5. If bins remain in the interior with counts less than 5, `chi2gof` displays a warning. In this case, you should use fewer bins, or provide bin centers or edges, to increase the expected counts in all bins. (See the syntax for specifying optional argument `name/value` pairs below.) `chi2gof` sets the number of bins, `nbins`, to 10 by default, and compares the test statistic to a chi-square distribution with `nbins - 3` degrees of freedom to take into account the two estimated parameters.

`[h,p] = chi2gof(...)` also returns the p value of the test, p . The p value is the probability, under assumption of the null hypothesis, of observing the given statistic or one more extreme.

`[h,p,stats] = chi2gof(...)` also returns a structure `stats` with the following fields:

- `chi2stat` — The chi-square statistic
- `df` — Degrees of freedom
- `edges` — Vector of bin edges after pooling
- `O` — Observed count in each bin
- `E` — Expected count in each bin

`[...] = chi2gof(X, 'Name', value)` specifies one or more optional argument name/value pairs chosen from the following lists. Argument names are case insensitive and partial matches are allowed. Specify *Name* in single quotes.

The following name/value pairs control the initial binning of the data before pooling. You should not specify more than one of these options.

- `nbins` — The number of bins to use. Default is 10.
- `ctrs` — A vector of bin centers
- `edges` — A vector of bin edges

The following name/value pairs determine the null distribution for the test. Do not specify both `cdf` and `expected`.

- `cdf` — A fully specified cumulative distribution function. This can be a function name, a function handle, or a `ProbDist` object of the `ProbDistUnivParam` class or `ProbDistUnivKernel` class. When `'cdf'` is a function name or handle, the distribution function must take `x` as its only argument. Alternately, you can provide a cell array whose first element is a function name or handle, and whose later elements are parameter values, one per cell. The function must take `x` as its first argument, and other parameters as later arguments.

- `expected` — A vector with one element per bin specifying the expected counts for each bin.
- `nparams` — The number of estimated parameters; used to adjust the degrees of freedom to be $\text{nbins} - 1 - \text{nparams}$, where `nbins` is the number of bins.

If your `cdf` or `expected` input depends on estimated parameters, you should use `nparams` to ensure that the degrees of freedom for the test is correct. If `cdf` is a cell array, the default value of `nparams` is the number of parameters in the array; otherwise the default is 0.

The following name/value pairs control other aspects of the test.

- `emin` — The minimum allowed expected value for a bin; any bin in either tail having an expected value less than this amount is pooled with a neighboring bin. Use the value 0 to prevent pooling. The default is 5.
- `frequency` — A vector the same length as `x` containing the frequency of the corresponding `x` values
- `alpha` — Significance level for the test. The default is 0.05.

Examples

Example 1

Equivalent ways to test against an unspecified normal distribution with estimated parameters:

```
x = normrnd(50,5,100,1);
```

```
[h,p] = chi2gof(x)
```

```
h =
```

```
0
```

```
p =
```

```
0.7532
```

```
[h,p] = chi2gof(x, 'cdf', @(z) normcdf(z, mean(x), std(x)), 'nparams', 2)
```

```
h =
```

```
0
```

```
p =
```

```
0.7532
```

```
[h,p] = chi2gof(x,'cdf',{@normcdf,mean(x),std(x)})  
h =  
    0  
p =  
    0.7532
```

Example 2

Test against the standard normal:

```
x = randn(100,1);
```

```
[h,p] = chi2gof(x,'cdf',@normcdf)  
h =  
    0  
p =  
    0.9443
```

Example 3

Test against the standard uniform:

```
x = rand(100,1);  
  
n = length(x);  
edges = linspace(0,1,11);  
expectedCounts = n * diff(edges);  
[h,p,st] = chi2gof(x,'edges',edges,...  
                  'expected',expectedCounts)  
h =  
    0  
p =  
    0.3191  
st =  
    chi2stat: 10.4000  
           df: 9  
           edges: [1x11 double]
```

```
0: [6 11 4 12 15 8 14 9 11 10]
E: [1x10 double]
```

Example 4

Test against the Poisson distribution by specifying observed and expected counts:

```
bins = 0:5;
obsCounts = [6 16 10 12 4 2];
n = sum(obsCounts);
lambdaHat = sum(bins.*obsCounts)/n;
expCounts = n*poisspdf(bins,lambdaHat);

[h,p,st] = chi2gof(bins,'ctrs',bins,...
                  'frequency',obsCounts, ...
                  'expected',expCounts,...
                  'nparams',1)

h =
    0
p =
    0.4654
st =
    chi2stat: 2.5550
           df: 3
           edges: [1x6 double]
                  0: [6 16 10 12 6]
                  E: [7.0429 13.8041 13.5280 8.8383 6.0284]
```

See Also

[crosstab](#) | [lillietest](#) | [kstest](#) | [chi2cdf](#) | [chi2pdf](#) | [chi2inv](#) | [chi2stat](#) | [chi2rnd](#)

How To

- “Chi-Square Distribution” on page B-25

Purpose Chi-square inverse cumulative distribution function

Syntax `X = chi2inv(P,V)`

Description `X = chi2inv(P,V)` computes the inverse of the chi-square cdf with degrees of freedom specified by `V` for the corresponding probabilities in `P`. `P` and `V` can be vectors, matrices, or multidimensional arrays that have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs.

The degrees of freedom parameters in `V` must be positive integers, and the values in `P` must lie in the interval `[0 1]`.

The inverse chi-square cdf for a given probability p and v degrees of freedom is

$$x = F^{-1}(p | v) = \{x : F(x | v) = p\}$$

where

$$p = F(x | v) = \int_0^x \frac{t^{(v-2)/2} e^{-t/2}}{2^{v/2} \Gamma(v/2)} dt$$

and $\Gamma(\cdot)$ is the Gamma function. Each element of output `X` is the value whose cumulative probability under the chi-square cdf defined by the corresponding degrees of freedom parameter in `V` is specified by the corresponding value in `P`.

Examples

Find a value that exceeds 95% of the samples from a chi-square distribution with 10 degrees of freedom.

```
x = chi2inv(0.95,10)
x =
    18.3070
```

You would observe values greater than 18.3 only 5% of the time by chance.

chi2inv

See Also

`icdf` | `chi2cdf` | `chi2pdf` | `chi2stat` | `chi2rnd`

How To

- “Chi-Square Distribution” on page B-25

Purpose Chi-square probability density function

Syntax `Y = chi2pdf(X,V)`

Description `Y = chi2pdf(X,V)` computes the chi-square pdf at each of the values in `X` using the corresponding degrees of freedom in `V`. `X` and `V` can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of the output `Y`. A scalar input is expanded to a constant array with the same dimensions as the other input.

The degrees of freedom parameters in `V` must be positive integers, and the values in `X` must lie on the interval `[0 Inf]`.

The chi-square pdf for a given value x and ν degrees of freedom is

$$y = f(x | \nu) = \frac{x^{(\nu-2)/2} e^{-x/2}}{2^{\nu/2} \Gamma(\nu / 2)}$$

where $\Gamma(\cdot)$ is the Gamma function.

If x is standard normal, then x^2 is distributed chi-square with one degree of freedom. If x_1, x_2, \dots, x_n are n independent standard normal observations, then the sum of the squares of the x 's is distributed chi-square with n degrees of freedom (and is equivalent to the gamma density function with parameters $\nu/2$ and 2).

Examples

```
nu = 1:6;
x = nu;
y = chi2pdf(x,nu)
y =
    0.2420    0.1839    0.1542    0.1353    0.1220    0.1120
```

The mean of the chi-square distribution is the value of the degrees of freedom parameter, `nu`. The above example shows that the probability density of the mean falls as `nu` increases.

See Also

`pdf` | `chi2cdf` | `chi2inv` | `chi2stat` | `chi2rnd`

How To

- “Chi-Square Distribution” on page B-25

Purpose	Chi-square random numbers
Syntax	<pre>R = chi2rnd(V) R = chi2rnd(V,m,n,...) R = chi2rnd(V,[m,n,...])</pre>
Description	<p>R = chi2rnd(V) generates random numbers from the chi-square distribution with degrees of freedom parameters specified by V. V can be a vector, a matrix, or a multidimensional array. R is the same size as V.</p> <p>R = chi2rnd(V,m,n,...) or R = chi2rnd(V,[m,n,...]) generates an m-by-n-by-... array containing random numbers from the chi-square distribution with degrees of freedom parameter V. V can be a scalar or an array of the same size as R.</p>
Examples	<p>Note that the first and third commands are the same, but are different from the second command.</p> <pre>r = chi2rnd(1:6) r = 0.0037 3.0377 7.8142 0.9021 3.2019 9.0729</pre> <pre>r = chi2rnd(6,[1 6]) r = 6.5249 2.6226 12.2497 3.0388 6.3133 5.0388</pre> <pre>r = chi2rnd(1:6,1,6) r = 0.7638 6.0955 0.8273 3.2506 1.5469 10.9197</pre>
See Also	random chi2cdf chi2pdf chi2inv chi2stat
How To	<ul style="list-style-type: none">• “Chi-Square Distribution” on page B-25

chi2stat

Purpose Chi-square mean and variance

Syntax [M,V] = chi2stat(NU)

Description [M,V] = chi2stat(NU) returns the mean of and variance for the chi-square distribution with degrees of freedom parameters specified by NU.

The mean of the chi-square distribution is v , the degrees of freedom parameter, and the variance is $2v$.

Examples

```
nu = 1:10;
nu = nu'*nu;
[m,v] = chi2stat(nu)
m =
    1     2     3     4     5     6     7     8     9    10
    2     4     6     8    10    12    14    16    18    20
    3     6     9    12    15    18    21    24    27    30
    4     8    12    16    20    24    28    32    36    40
    5    10    15    20    25    30    35    40    45    50
    6    12    18    24    30    36    42    48    54    60
    7    14    21    28    35    42    49    56    63    70
    8    16    24    32    40    48    56    64    72    80
    9    18    27    36    45    54    63    72    81    90
   10    20    30    40    50    60    70    80    90   100

v =
    2     4     6     8    10    12    14    16    18    20
    4     8    12    16    20    24    28    32    36    40
    6    12    18    24    30    36    42    48    54    60
    8    16    24    32    40    48    56    64    72    80
   10    20    30    40    50    60    70    80    90   100
   12    24    36    48    60    72    84    96   108   120
   14    28    42    56    70    84    98   112   126   140
   16    32    48    64    80    96   112   128   144   160
   18    36    54    72    90   108   126   144   162   180
   20    40    60    80   100   120   140   160   180   200
```

See Also

[chi2cdf](#) | [chi2pdf](#) | [chi2inv](#) | [chi2rnd](#)

How To

- “Chi-Square Distribution” on page B-25

classregtree.children

Purpose Child nodes

Syntax `C = children(t)`
`C = children(t,nodes)`

Description `C = children(t)` returns an n -by-2 array `C` containing the numbers of the child nodes for each node in the tree `t`, where n is the number of nodes. Leaf nodes have child node 0.

`C = children(t,nodes)` takes a vector `nodes` of node numbers and returns the children for the specified nodes.

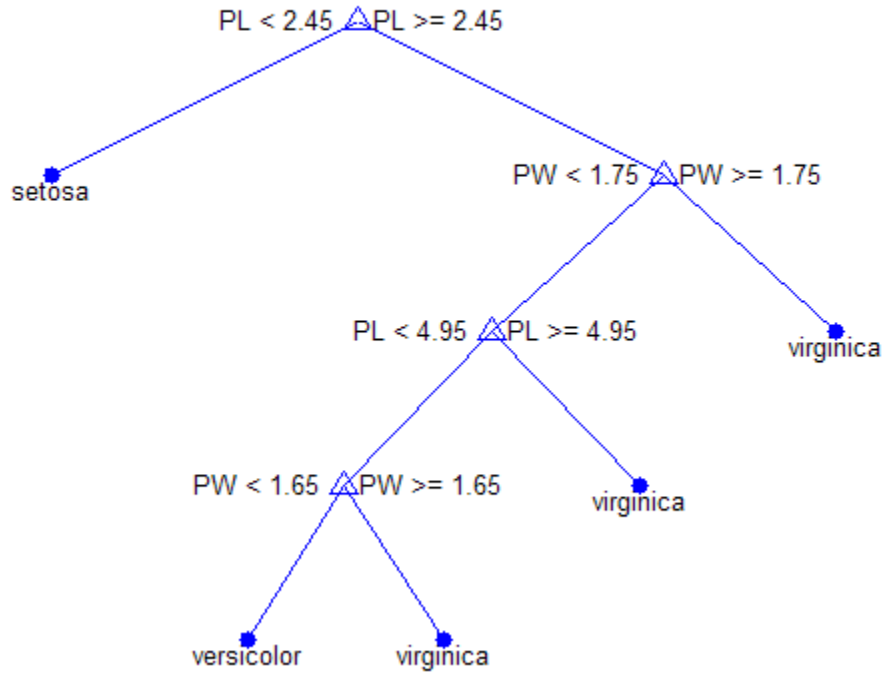
Examples Create a classification tree for Fisher's iris data:

```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

Click to display: Magnification: Pruning level:



C = children(t)

```

C =
     2     3
     0     0
     4     5
     6     7
     0     0
     8     9
     0     0
     0     0
  
```

classregtree.children

0 0

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

`classregtree` | `numnodes` | `parent`

Purpose Cholesky-like covariance decomposition

Syntax

```
T = cholcov(SIGMA)
[T,num] = cholcov(SIGMA)
[T,num] = cholcov(SIGMA,0)
```

Description `T = cholcov(SIGMA)` computes `T` such that `SIGMA = T'*T`. `SIGMA` must be square, symmetric, and positive semi-definite. If `SIGMA` is positive definite, then `T` is the square, upper triangular Cholesky factor. If `SIGMA` is not positive definite, `T` is computed from an eigenvalue decomposition of `SIGMA`. `T` is not necessarily triangular or square in this case. Any eigenvectors whose corresponding eigenvalue is close to zero (within a small tolerance) are omitted. If any remaining eigenvalues are negative, `T` is empty.

`[T,num] = cholcov(SIGMA)` returns the number `num` of negative eigenvalues of `SIGMA`, and `T` is empty if `num` is positive. If `num` is zero, `SIGMA` is positive semi-definite. If `SIGMA` is not square and symmetric, `num` is NaN and `T` is empty.

`[T,num] = cholcov(SIGMA,0)` returns `num` equal to zero if `SIGMA` is positive definite, and `T` is the Cholesky factor. If `SIGMA` is not positive definite, `num` is a positive integer and `T` is empty. `[...] = cholcov(SIGMA,1)` is equivalent to `[...] = cholcov(SIGMA)`.

Examples The following 4-by-4 covariance matrix is rank-deficient:

```
C1 = [2 1 1 2;1 2 1 2;1 1 2 2;2 2 2 3]
```

```
C1 =
```

```

     2     1     1     2
     1     2     1     2
     1     1     2     2
     2     2     2     3
```

```
rank(C1)
```

```
ans =
```

```

     3
```

Use `cholcov` to factor `C1`:

cholcov

```
T = cholcov(C1)
T =
    -0.2113    0.7887   -0.5774         0
     0.7887   -0.2113   -0.5774         0
     1.1547    1.1547    1.1547    1.7321
```

```
C2 = T'*T
C2 =
    2.0000    1.0000    1.0000    2.0000
    1.0000    2.0000    1.0000    2.0000
    1.0000    1.0000    2.0000    2.0000
    2.0000    2.0000    2.0000    3.0000
```

Use T to generate random data with the specified covariance:

```
C3 = cov(randn(1e6,3)*T)
C3 =
    1.9973    0.9982    0.9995    1.9975
    0.9982    1.9962    0.9969    1.9956
    0.9995    0.9969    1.9980    1.9972
    1.9975    1.9956    1.9972    2.9951
```

See Also

[chol](#) | [cov](#)

Purpose Shift categorical array circularly

Syntax `B = circshift(A, shiftsize)`

Description `B = circshift(A, shiftsize)` circularly shifts the values in the categorical array `A` by `shiftsize` elements. `shiftsize` is a vector of integer scalars where the `n`-th element specifies the shift amount for the `n`-th dimension of array `A`. If an element in `shiftsize` is positive, the values of `A` are shifted down (or to the right). If it is negative, the values of `A` are shifted up (or to the left).

See Also `permute` | `shiftdim`

NaiveBayes.CIsNonEmpty property

Purpose Flag for non-empty classes

Description The CIsNonEmpty property is a logical vector of length NClasses specifying which classes are not empty. When the grouping variable is categorical, it may contain categorical levels that don't appear in the elements of the grouping variable. Those levels are empty and NaiveBayes ignores them for the purposes of training the classifier.

Purpose

Class counts

Syntax

```
P = classcount(t)
P = classcount(t,nodes)
```

Description

`P = classcount(t)` returns an n -by- m array P of class counts for the nodes in the classification tree t , where n is the number of nodes and m is the number of classes. For any node number i , the class counts $P(i, :)$ are counts of observations (from the data used in fitting the tree) from each class satisfying the conditions for node i .

`P = classcount(t,nodes)` takes a vector `nodes` of node numbers and returns the class counts for the specified nodes.

Examples

Create a classification tree for Fisher's iris data:

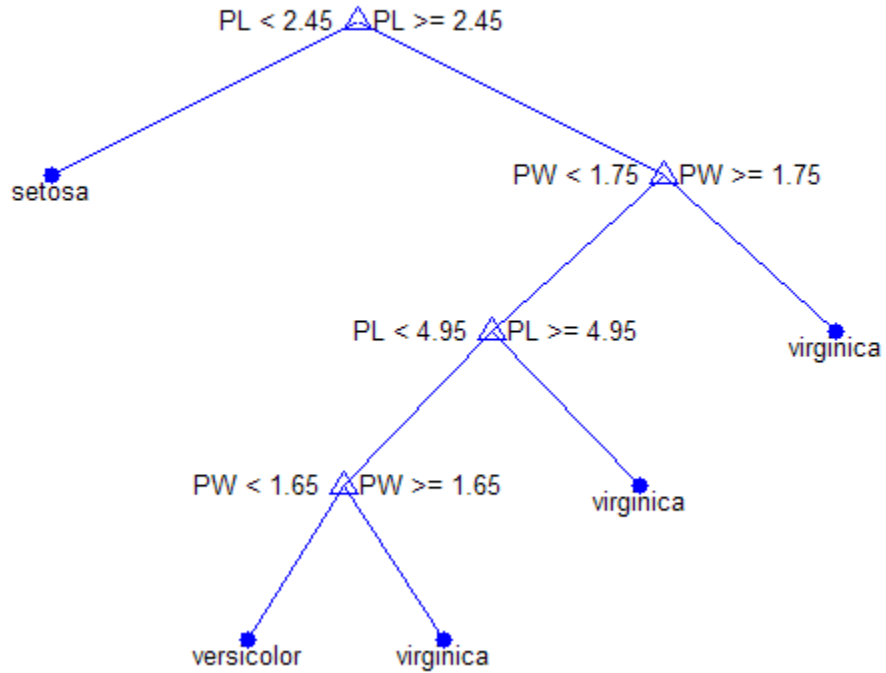
```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

classregtree.classcount

Click to display: Magnification: Pruning level:



P = classcount(t)

```
P =  
50  50  50  
50  0  0  
0  50  50  
0  49  5  
0  1  45  
0  47  1  
0  2  4  
0  47  0
```

0 0 1

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree | numnodes

ClassificationBaggedEnsemble

Purpose Classification ensemble grown by resampling

Description `ClassificationBaggedEnsemble` combines a set of trained weak learner models and data on which these learners were trained. It can predict ensemble response for new data by aggregating predictions from its weak learners.

Construction `ens = fitensemble(X,Y,'bag',nlearn,learners,'type','classification')` creates a bagged classification ensemble. For syntax details, see the `fitensemble` reference page.

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.

CombineWeights

String describing how `ens` combines weak learner weights, either `'WeightedSum'` or `'WeightedAverage'`.

FitInfo

Numeric array of fit information. The `FitInfoDescription` property describes the content of this array.

FitInfoDescription

String describing the meaning of the `FitInfo` array.

FResample

Numeric scalar between 0 and 1. `FResample` is the fraction of training data `fitensemble` resampled at random for every weak learner when constructing the ensemble.

Method

String describing the method that creates `ens`.

ModelParams

Parameters used in training `ens`.

NTrained

Number of trained weak learners in `ens`, a scalar.

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in `X`.

ReasonForTermination

String describing the reason `fitensemble` stopped adding weak learners to the ensemble.

Replace

Logical value indicating if the ensemble was trained with replacement (`true`) or without replacement (`false`).

ResponseName

String with the name of the response variable `Y`.

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means `@(x)x`. For a list of built-in transformation functions and the syntax of custom transformation functions, see `ClassificationTree.fit`.

Add or change a `ScoreTransform` function by dot addressing:

```
ens.ScoreTransform = 'function'
```

or

```
ens.ScoreTransform = @function
```

Trained

Trained learners, a cell array of compact classification models.

ClassificationBaggedEnsemble

TrainedWeights

Numeric vector of trained weights for the weak learners in `ens`. `TrainedWeights` has `T` elements, where `T` is the number of weak learners in `learners`.

UseObsForLearner

Logical matrix of size `N`-by-`NTrained`, where `N` is the number of observations in the training data and `NTrained` is the number of trained weak learners. `UseObsForLearner(I,J)` is `true` if observation `I` was used for training learner `J`, and is `false` otherwise.

W

Scaled `weights`, a vector with length `n`, the number of rows in `X`. The sum of the elements of `W` is 1.

X

Matrix of predictor values that trained the ensemble. Each column of `X` represents one variable, and each row represents one observation.

Y

Numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of `Y` represents the classification of the corresponding row of `X`.

Methods

<code>oobEdge</code>	Out-of-bag classification edge
<code>oobLoss</code>	Out-of-bag classification error
<code>oobMargin</code>	Out-of-bag classification margins
<code>oobPredict</code>	Predict out-of-bag response of ensemble

Inherited Methods

compact	Compact classification ensemble
crossval	Cross validate ensemble
resubEdge	Classification edge by resubstitution
resubLoss	Classification error by resubstitution
resubMargin	Classification margins by resubstitution
resubPredict	Predict ensemble response by resubstitution
resume	Resume training ensemble
edge	Classification edge
loss	Classification error
margin	Classification margins
predict	Predict classification
predictorImportance	Estimates of predictor importance
removeLearners	Remove members of compact classification ensemble

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Construct a bagged ensemble for the ionosphere data, and examine its resubstitution loss:

```
load ionosphere
rng(0,'twister') % for reproducibility
ens = fitensemble(X,Y,'bag',100,'Tree',...
```

ClassificationBaggedEnsemble

```
        'type','classification');  
L = resubLoss(ens)  
  
L =  
    0
```

The ensemble does a perfect job classifying its training data.

See Also

ClassificationEnsemble | fitensemble

How To

- “Ensemble Methods” on page 13-54

Superclasses	CompactClassificationDiscriminant
Purpose	Discriminant analysis classification
Description	A ClassificationDiscriminant object encapsulates a discriminant analysis classifier, which is a Gaussian mixture model for data generation. A ClassificationDiscriminant object can predict responses for new data using the predict method. The object contains the data used for training, so can compute resubstitution predictions.
Construction	<p><code>obj = ClassificationDiscriminant.fit(X,Y)</code> creates a discriminant classification object based on the input variables (also known as predictors, features, or attributes) <code>X</code> and output (response) <code>Y</code>. For syntax details, see <code>ClassificationDiscriminant.fit</code>.</p> <p><code>obj = ClassificationDiscriminant.fit(X,Y,Name,Value)</code> creates a classifier with additional options specified by one or more <code>Name, Value</code> pair arguments. If you use one of the following five options, <code>obj</code> is of class <code>ClassificationPartitionedModel</code>: <code>'crossval'</code>, <code>'kfold'</code>, <code>'holdout'</code>, <code>'leaveout'</code>, or <code>'cvpartition'</code>. Otherwise, <code>obj</code> is of class <code>ClassificationDiscriminant</code>.</p>

Input Arguments

X

Matrix of numeric predictor values. Each column of `X` represents one variable, and each row represents one observation.

NaN values in `X` are considered missing values. Observations with missing values for `X` are not used in the fit.

Y

Numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of `Y` represents the classification of the corresponding row of `X`. NaN values in `Y` are considered missing values. Observations with missing values for `Y` are not used in the fit.

ClassificationDiscriminant

Properties

BetweenSigma

p-by-p matrix, the between-class covariance, where p is the number of predictors.

CategoricalPredictors

List of categorical predictors, always empty ([]) for discriminant analysis.

ClassNames

List of the elements in the training data Y with duplicates removed. `ClassNames` can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. `ClassNames` has the same data type as the data in the argument Y.

Coeffs

k-by-k structure of coefficient matrices, where k is the number of classes. `Coeffs(i, j)` contains coefficients of the linear or quadratic boundaries between classes i and j. Fields in `Coeffs(i, j)`:

- `DiscrimType`
- `Class1` — `ClassNames(i)`
- `Class2` — `ClassNames(j)`
- `Const` — A scalar
- `Linear` — A vector with p components, where p is the number of columns in X
- `Quadratic` — p-by-p matrix, exists for quadratic `DiscrimType`

The equation of the boundary between class i and class j is

$$\text{Const} + \text{Linear} * x + x' * \text{Quadratic} * x = 0,$$

where x is a column vector of length p.

If `ClassificationDiscriminant.fit` had the `FillCoeffs` name-value pair set to 'off' when constructing the classifier, `Coeffs` is empty (`[]`).

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class `j` if its true class is `i`. `Cost` is `K-by-K`, where `K` is the number of classes.

Change a `Cost` matrix using dot addressing:

```
obj.Cost = costMatrix
```

Delta

Value of the `Delta` threshold for a linear discriminant model, a nonnegative scalar. If a coefficient of `obj` has magnitude smaller than `Delta`, `obj` sets this coefficient to 0, and so you can eliminate the corresponding predictor from the model. Set `Delta` to a higher value to eliminate more predictors.

`Delta` must be 0 for quadratic discriminant models.

Change `Delta` by dot addressing:

```
obj.Delta = newDelta
```

DeltaPredictor

Row vector of length equal to the number of predictors in `obj`. If `DeltaPredictor(i) < Delta` then coefficient `i` of the model is 0.

If `obj` is a quadratic discriminant model, all elements of `DeltaPredictor` are 0.

DiscrimType

String specifying the discriminant type. One of:

- 'linear'
- 'quadratic'

ClassificationDiscriminant

- 'diagLinear'
- 'diagQuadratic'
- 'pseudoLinear'
- 'pseudoQuadratic'

Change DiscrimType using dot addressing:

```
obj.DiscrimType = newDiscrimType
```

You can change between linear types, or between quadratic types, but cannot change between linear and quadratic types.

Gamma

Value of the Gamma regularization parameter, a scalar from 0 to 1. Change Gamma using dot addressing:

```
obj.Gamma = newGamma
```

- If you set 1 for linear discriminant, the discriminant sets its type to 'diagLinear'.
- If you set a value between MinGamma and 1 for linear discriminant, the discriminant sets its type to 'linear'.
- You cannot set values below the value of the MinGamma property.
- For quadratic discriminant, you can set either 0 (for DiscrimType 'quadratic') or 1 (for DiscrimType 'diagQuadratic').

LogDetSigma

Logarithm of the determinant of the within-class covariance matrix. The type of LogDetSigma depends on the discriminant type:

- Scalar for linear discriminant analysis

- Vector of length K for quadratic discriminant analysis, where K is the number of classes

MinGamma

Nonnegative scalar, the minimal value of the Gamma parameter so that the correlation matrix is invertible. If the correlation matrix is not singular, MinGamma is 0.

ModelParams

Parameters used in training obj.

Mu

Matrix of class means of size K -by- p , where K is the number of classes, and p is the number of predictors. Each row of Mu represents the mean of the multivariate normal distribution of the corresponding class. The class indices are in the `ClassNames` attribute.

NObservations

Number of observations in the training data, a numeric scalar. `NObservations` can be less than the number of rows of input data X when there are missing values in X or response Y .

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in the training data X .

Prior

Prior probabilities for each class. `Prior` is a numeric vector whose entries relate to the corresponding `ClassNames` property.

Add or change a `Prior` vector using dot addressing:

```
obj.Prior = priorVector
```

ResponseName

String describing the response variable Y .

ClassificationDiscriminant

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$. For a list of built-in transformation functions and the syntax of custom transformation functions, see `ClassificationDiscriminant.fit`.

Add or change a `ScoreTransform` function by dot addressing:

```
cobj.ScoreTransform = 'function'
```

or

```
cobj.ScoreTransform = @function
```

Sigma

Within-class covariance matrix or matrices. The dimensions depend on `DiscrimType`:

- 'linear' (default) — Matrix of size p -by- p , where p is the number of predictors
- 'quadratic' — Array of size p -by- p -by- K , where K is the number of classes
- 'diagLinear' — Row vector of length p
- 'diagQuadratic' — Array of size 1 -by- p -by- K
- 'pseudoLinear' — Matrix of size p -by- p
- 'pseudoQuadratic' — Array of size p -by- p -by- K

W

Scaled weights, a vector with length n , the number of rows in X .

X

Matrix of predictor values. Each column of X represents one predictor (variable), and each row represents one observation.

Xcentered

X data with class means subtracted. If $Y(i)$ is of class j ,

$$Xcentered(i,:) = X(i,:) - Mu(j,:),$$

where Mu is the class mean property.

Y

Numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of Y represents the classification of the corresponding row of X .

Methods

compact	Compact discriminant analysis classifier
crossval	Cross-validated discriminant analysis classifier
cvshrink	Cross-validate regularization of linear discriminant
fit	Fit discriminant analysis classifier
make	Construct discriminant analysis classifier from parameters
resubEdge	Classification edge by resubstitution
resubLoss	Classification error by resubstitution
resubMargin	Classification margins by resubstitution

ClassificationDiscriminant

resubPredict	Predict resubstitution response of classifier
template	Discriminant analysis classifier template for ensemble

Inherited Methods

edge	Classification edge
logP	Log of the unconditional probability density
loss	Classification error
mahal	Mahalanobis distance to class means
margin	Classification margins
nLinearCoeffs	Number of nonzero linear coefficients
predict	Predict classification

Definitions

Discriminant Classification

The model for discriminant analysis is:

- Each class (Y) generates data (X) using a multivariate normal distribution. That is, the model assumes X has a Gaussian mixture distribution (`gmdistribution`).
 - For linear discriminant analysis, the model has the same covariance matrix for each class, only the means vary.
 - For quadratic discriminant analysis, both means and covariances of each class vary.

`predict` classifies so as to minimize the expected classification cost:

$$\hat{y} = \arg \min_{y=1, \dots, K} \sum_{k=1}^K \hat{P}(k | x) C(y | k),$$

where

- \hat{y} is the predicted classification.
- K is the number of classes.
- $\hat{P}(k | x)$ is the posterior probability of class k for observation x .
- $C(y | k)$ is the cost of classifying an observation as y when its true class is k .

For details, see “How the predict Method Classifies” on page 12-6.

Regularization

Regularization is the process of finding a small set of predictors that yield an effective predictive model. For linear discriminant analysis, there are two parameters, γ and δ , that control regularization as follows. `cvshrink` helps you select appropriate values of the parameters.

Let Σ represent the covariance matrix of the data X , and let \hat{X} be the centered data (the data X minus the mean by class). Define

$$D = \text{diag}(\hat{X}^T * \hat{X}).$$

The regularized covariance matrix $\tilde{\Sigma}$ is

$$\tilde{\Sigma} = (1 - \gamma)\Sigma + \gamma D.$$

Whenever $\gamma \geq \text{MinGamma}$, $\tilde{\Sigma}$ is nonsingular.

Let μ_k be the mean vector for those elements of X in class k , and let μ_0 be the global mean vector (the mean of the rows of X). Let C be

ClassificationDiscriminant

the correlation matrix of the data X , and let \tilde{C} be the regularized correlation matrix:

$$\tilde{C} = (1 - \gamma)C + \gamma I,$$

where I is the identity matrix.

The linear term in the regularized discriminant analysis classifier for a data point x is

$$(x - \mu_0)^T \tilde{\Sigma}^{-1} (\mu_k - \mu_0) = \left[(x - \mu_0)^T D^{-1/2} \right] \left[\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right].$$

The parameter δ enters into this equation as a threshold on the final term in square brackets. Each component of the vector

$\left[\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right]$ is set to zero if it is smaller in magnitude than the threshold δ . Therefore, for class k , if component j is thresholded to zero, component j of x does not enter into the evaluation of the posterior probability.

The `DeltaPredictor` property is a vector related to this threshold. When $\delta \geq \text{DeltaPredictor}(i)$, all classes k have

$$\left| \tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right| \leq \delta.$$

Therefore, when $\delta \geq \text{DeltaPredictor}(i)$, the regularized classifier does not use predictor i .

Copy Semantics

Value. To learn how value classes affect copy operations, see [Copying Objects in the MATLAB Programming Fundamentals documentation](#).

Examples

Create a discriminant analysis classifier for the Fisher iris data:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species)
```

```
obj =  
ClassificationDiscriminant:  
  PredictorNames: {'x1' 'x2' 'x3' 'x4'}  
  ResponseName: 'Y'  
  ClassNames: {'setosa' 'versicolor' 'virginica'}  
  ScoreTransform: 'none'  
  NObservations: 150  
  DiscrimType: 'linear'  
    Mu: [3x4 double]  
    Coeffs: [3x3 struct]
```

References

[1] Guo, Y., T. Hastie, and R. Tibshirani. *Regularized linear discriminant analysis and its application in microarrays*. *Biostatistics*, Vol. 8, No. 1, pp. 86–100, 2007.

See Also

CompactClassificationDiscriminant |
ClassificationDiscriminant.fit

How To

- “Discriminant Analysis” on page 12-3

ClassificationEnsemble

Superclasses CompactClassificationEnsemble

Purpose Ensemble classifier

Description ClassificationEnsemble combines a set of trained weak learner models and data on which these learners were trained. It can predict ensemble response for new data by aggregating predictions from its weak learners. It also stores data used for training and can compute resubstitution predictions. It can resume training if desired.

Construction `ens = fitensemble(X,Y,method,nlearn,learners)` returns an ensemble model that can predict responses to data. The ensemble consists of models listed in `learners`. For more information on the syntax, see the `fitensemble` function reference page.

`ens = fitensemble(X,Y,method,nlearn,learners,Name,Value)` returns an ensemble model with additional options specified by one or more `Name,Value` pair arguments. For more information on the syntax, see the `fitensemble` function reference page.

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.

ClassNames

List of the elements in `Y` with duplicates removed. `ClassNames` can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. `ClassNames` has the same data type as the data in the argument `Y`.

CombineWeights

String describing how `ens` combines weak learner weights, either `'WeightedSum'` or `'WeightedAverage'`.

Cost

Square matrix where $\text{Cost}(i, j)$ is the cost of classifying a point into class j if its true class is i .

FitInfo

Numeric array of fit information. The `FitInfoDescription` property describes the content of this array.

FitInfoDescription

String describing the meaning of the `FitInfo` array.

LearnerNames

Cell array of strings with names of weak learners in the ensemble. The name of each learner appears just once. For example, if you have an ensemble of 100 trees, `LearnerNames` is `{'Tree'}`.

Method

String describing the method that creates `ens`.

ModelParams

Parameters used in training `ens`.

NObservations

Numeric scalar containing the number of observations in the training data.

NTrained

Number of trained weak learners in `ens`, a scalar.

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in X .

Prior

Prior probabilities for each class. `Prior` is a numeric vector whose entries relate to the corresponding `ClassNames` property.

ReasonForTermination

ClassificationEnsemble

String describing the reason `fitensemble` stopped adding weak learners to the ensemble.

ResponseName

String with the name of the response variable `Y`.

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$. For a list of built-in transformation functions and the syntax of custom transformation functions, see `ClassificationTree.fit`.

Add or change a `ScoreTransform` function by dot addressing:

```
ens.ScoreTransform = 'function'
```

or

```
ens.ScoreTransform = @function
```

Trained

Trained learners, a cell array of compact classification models.

TrainedWeights

Numeric vector of trained weights for the weak learners in `ens`. `TrainedWeights` has `T` elements, where `T` is the number of weak learners in `learners`.

UsePredForLearner

Logical matrix of size `P`-by-`NTrained`, where `P` is the number of predictors (columns) in the training data `X`. `UsePredForLearner(i, j)` is `true` when learner `j` uses predictor `i`, and is `false` otherwise. For each learner, the predictors have the same order as the columns in the training data `X`.

If the ensemble is not of type `Subspace`, all entries in `UsePredForLearner` are `true`.

W

Scaled **w**eights, a vector with length n , the number of rows in X . The sum of the elements of W is 1.

X

Matrix of predictor values that trained the ensemble. Each column of X represents one variable, and each row represents one observation.

Y

Numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of Y represents the classification of the corresponding row of X .

Methods

compact	Compact classification ensemble
crossval	Cross validate ensemble
resubEdge	Classification edge by resubstitution
resubLoss	Classification error by resubstitution
resubMargin	Classification margins by resubstitution
resubPredict	Predict ensemble response by resubstitution
resume	Resume training ensemble

Inherited Methods

edge	Classification edge
loss	Classification error

ClassificationEnsemble

margin	Classification margins
predict	Predict classification
predictorImportance	Estimates of predictor importance
removeLearners	Remove members of compact classification ensemble

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Construct a boosted classification ensemble for the ionosphere data, using the AdaBoostM1 method:

```
load ionosphere
ens = fitensemble(X,Y,'AdaBoostM1',100,'Tree')

ens =
classreg.learning.classif.ClassificationEnsemble:
    PredictorNames: {1x34 cell}
    CategoricalPredictors: []
    ResponseName: 'Response'
    ClassNames: {'b' 'g'}
    ScoreTransform: 'none'
    NObservations: 351
    NTrained: 100
    Method: 'AdaBoostM1'
    LearnerNames: {'Tree'}
    ReasonForTermination: [1x77 char]
    FitInfo: [100x1 double]
    FitInfoDescription: [2x83 char]
```

Predict the classification of the mean of X:

```
ypredict = predict(ens,mean(X))

ypredict =
```

'g'

See Also

ClassificationTree | fitensemble | RegressionEnsemble |
CompactClassificationEnsemble

ClassificationKNN

Purpose *k*-nearest neighbor classification

Description A nearest-neighbor classification object, where both distance metric (“nearest”) and number of neighbors can be altered. The object classifies new observations using the `predict` method. The object contains the data used for training, so can compute resubstitution predictions.

Construction `mdl = ClassificationKNN.fit(X,Y)` creates a *k*-nearest neighbor classification model. For details, see `ClassificationKNN.fit`.

`mdl = ClassificationKNN.fit(X,Y,Name,Value)` creates a classifier with additional options specified by one or more `Name,Value` pair arguments. For details, see `ClassificationKNN.fit`.

Input Arguments

X

Matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

Y

Grouping variables of response values with the same number of elements (rows) as X. Each entry in Y is the response to the data in the corresponding row of X.

Properties

BreakTies

String specifying the method `predict` uses to break ties if multiple classes have the same smallest cost. By default, ties occur when multiple classes have the same number of nearest points among the K nearest neighbors.

- 'nearest' — Use the class with the nearest neighbor among tied groups.
- 'random' — Use a random tiebreaker among tied groups.
- 'smallest' — Use the smallest index among tied groups.

'BreakTies' applies when 'IncludeTies' is false.

Change BreakTies using dot addressing:

```
mdl.BreakTies = newBreakTies
```

CategoricalPredictors

Specification of which predictors are categorical.

- 'all' — All predictors are categorical.
- [] — No predictors are categorical.

ClassNames

List of elements in the training data Y with duplicates removed. ClassNames can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. ClassNames has the same data type as the data in the argument Y.

Change ClassNames using dot addressing:

```
mdl.ClassNames = newClassNames
```

Cost

Square matrix, where $Cost(i, j)$ is the cost of classifying a point into class j if its true class is i . Cost is K-by-K, where K is the number of classes.

Change a Cost matrix using dot addressing:

```
mdl.Cost = costMatrix
```

Distance

String or function handle specifying the distance metric. The allowable strings depend on the NSMethod parameter, which you set in ClassificationKNN.fit, and which exists as a field in ModelParams.

ClassificationKNN

NSMethod	Distance Metric Names
exhaustive	Any distance metric of ExhaustiveSearcher
kdtree	'cityblock', 'chebychev', 'euclidean', or 'minkowski'

For definitions, see “Distance Metrics” on page 13-9.

The distance metrics of ExhaustiveSearcher:

Value	Description
'cityblock'	City block distance.
'chebychev'	Chebychev distance (maximum coordinate difference).
'correlation'	One minus the sample linear correlation between observations (treated as sequences of values).
'cosine'	One minus the cosine of the included angle between observations (treated as vectors).
'euclidean'	Euclidean distance.
'hamming'	Hamming distance, percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, the percentage of nonzero coordinates that differ.
'mahalanobis'	Mahalanobis distance, computed using a positive definite covariance matrix C . The default value of C is the sample covariance matrix of X , as computed by <code>nancov(X)</code> . To specify a different value for C , use the 'Cov' name-value pair.

Value	Description
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use the 'P' name-value pair.
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between X and a query point is scaled, meaning divided by a scale value S. The default value of S is the standard deviation computed from X, $S = \text{nanstd}(X)$. To specify another value for S, use the Scale name-value pair.
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
@distfun	<p>Distance function handle. <i>distfun</i> has the form</p> <pre>function D2 = DISTFUN(ZI,ZJ) % calculation of distance ...</pre> <p>where</p> <ul style="list-style-type: none"> • ZI is a 1-by-N vector containing one row of X or Y. • ZJ is an M2-by-N matrix containing multiple rows of X or Y. • D2 is an M2-by-1 vector of distances, and $D2(k)$ is the distance between observations ZI and $ZJ(J, :)$.

Change Distance using dot addressing:

```
mdl.Distance = newDistance
```

ClassificationKNN

If NSMethod is kdtree, you can use dot addressing to change Distance only among the types 'cityblock', 'chebychev', 'euclidean', or 'minkowski'.

DistanceWeight

String or function handle specifying the distance weighting function.

DistanceWeight	Meaning
'equal'	No weighting
'inverse'	Weight is 1/distance
'inversesquared'	Weight is 1/distance ²
@fcn	<i>fcn</i> is a function that accepts a matrix of nonnegative distances, and returns a matrix the same size containing nonnegative distance weights. For example, 'inversesquared' is equivalent to @(d)d.^(-2).

Change DistanceWeight using dot addressing:

```
mdl.DistanceWeight = newDistanceWeight
```

DistParameter

Additional parameter for the distance metric.

Distance Metric	Parameter
'mahalanobis'	Positive definite covariance matrix C.
'minkowski'	Minkowski distance exponent, a positive scalar.
'seuclidean'	Vector of positive scale values with length equal to the number of columns of X.

For values of the distance metric other than those in the table, `DistParameter` must be []. Change `DistParameter` using dot addressing:

```
mdl.DistParameter = newDistParameter
```

IncludeTies

Logical value indicating whether `predict` includes all the neighbors whose distance values are equal to the Kth smallest distance. If `IncludeTies` is `true`, `predict` includes all these neighbors. Otherwise, `predict` uses exactly K neighbors (see `'BreakTies'`).

Change `IncludeTies` using dot addressing:

```
mdl.IncludeTies = newIncludeTies
```

ModelParams

Parameters used in training `mdl`.

NObservations

Number of observations used in training `mdl`. This can be less than the number of rows in the training data, because data rows containing NaN values are not part of the fit.

NumNeighbors

Positive integer specifying the number of nearest neighbors in `X` to find for classifying each point when predicting. Change `NumNeighbors` using dot addressing:

```
mdl.NumNeighbors = newNumNeighbors
```

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in the training data `X`. Change `PredictorNames` using dot addressing:

ClassificationKNN

```
mdl.PredictorNames = newPredictorNames
```

Prior

Prior probabilities for each class. **Prior** is a numeric vector whose entries relate to the corresponding **ClassNames** property.

Add or change a **Prior** vector using dot addressing:

```
obj.Prior = priorVector
```

ResponseName

String describing the response variable **Y**. Change **ResponseName** using dot addressing:

```
mdl.ResponseName = newResponseName
```

W

Numeric vector of nonnegative weights with the same number of rows as **Y**. Each entry in **W** specifies the relative importance of the corresponding observation in **Y**. Change **W** using dot addressing:

```
mdl.W = newW
```

X

Numeric matrix of predictor values. Each column of **X** represents one predictor (variable), and each row represents one observation.

Y

Numeric vector of response values with the same number of rows as **X**. Each entry in **Y** is the response to the data in the corresponding row of **X**.

Methods

crossval	Cross-validated k -nearest neighbor classifier
edge	Edge of k -nearest neighbor classifier
fit	Fit k -nearest neighbor classifier
loss	Loss of k -nearest neighbor classifier
margin	Margin of k -nearest neighbor classifier
predict	Predict k -nearest neighbor classification
resubEdge	Edge of k -nearest neighbor classifier by resubstitution
resubLoss	Loss of k -nearest neighbor classifier by resubstitution
resubMargin	Margin of k -nearest neighbor classifier by resubstitution
resubPredict	Predict resubstitution response of k -nearest neighbor classifier
template	k -nearest neighbor classifier template for ensemble

Definitions

Prediction

ClassificationKNN predicts the classification of a point X_{new} using a procedure equivalent to this:

- 1 Find the NumNeighbors points in the training set X that are nearest to X_{new} .
- 2 Find the NumNeighbors response values Y to those nearest points.

ClassificationKNN

3 Assign the classification label Y_{new} that has smallest expected misclassification cost among the values in Y .

For details, see “Posterior Probability” on page 20-1830 and “Expected Cost” on page 20-1831 in the `predict` documentation.

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Construct a KNN Classifier

Construct a k -nearest neighbor classifier for the Fisher iris data, where $k = 5$.

Load the data.

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',5)
```

```
mdl =
```

```
ClassificationKNN:
  PredictorNames: {'x1' 'x2' 'x3' 'x4'}
  ResponseName: 'Y'
  ClassNames: {'setosa' 'versicolor' 'virginica'}
  ScoreTransform: 'none'
  NObservations: 150
  Distance: 'euclidean'
  NumNeighbors: 5
```

Alternatives

`knnsearch` finds the k -nearest neighbors of points. `rangesearch` finds all the points within a fixed distance. You can use these functions for classification, as shown in “Example: Classifying Query

Data Using `knnsearch`” on page 13-18. If you want to perform classification, `ClassificationKNN` can be more convenient, in that you can construct a classifier in one step and classify in other steps. Also, `ClassificationKNN` has cross-validation options.

See Also

`ClassificationKNN.fit` | `predict` |

Related Examples

- “Construct a KNN Classifier” on page 13-25
- “Examine the Quality of a KNN Classifier” on page 13-26
- “Predict Classification Based on a KNN Classifier” on page 13-27
- “Modify a KNN Classifier” on page 13-27

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

ClassificationPartitionedEnsemble

Purpose Cross-validated classification ensemble

Description `ClassificationPartitionedEnsemble` is a set of classification ensembles trained on cross-validated folds. Estimate the quality of classification by cross validation using one or more “kfold” methods: `kfoldPredict`, `kfoldLoss`, `kfoldMargin`, `kfoldEdge`, and `kfoldfun`.

Every “kfold” method uses models trained on in-fold observations to predict response for out-of-fold observations. For example, suppose you cross validate using five folds. In this case, every training fold contains roughly $4/5$ of the data and every test fold contains roughly $1/5$ of the data. The first model stored in `Trained{1}` was trained on X and Y with the first $1/5$ excluded, the second model stored in `Trained{2}` was trained on X and Y with the second $1/5$ excluded, and so on. When you call `kfoldPredict`, it computes predictions for the first $1/5$ of the data using the first model, for the second $1/5$ of data using the second model, and so on. In short, response for every observation is computed by `kfoldPredict` using the model trained without this observation.

Construction `cvens = crossval(ens)` creates a cross-validated ensemble from `ens`, a classification ensemble. For syntax details, see the `crossval` method reference page.

`cvens = fitensemble(X,Y,method,nlearn,learners,name,value)` creates a cross-validated ensemble when `name` is one of 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'. For syntax details, see the `fitensemble` function reference page.

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to p , where p is the number of columns of X .

ClassNames

List of the elements in Y with duplicates removed. `ClassNames` can be a numeric vector, vector of categorical variables (nominal

or ordinal), logical vector, character array, or cell array of strings. `ClassNames` has the same data type as the data in the argument `Y`.

Combiner

Cell array of combiners across all folds.

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class `j` if its true class is `i`.

CrossValidatedModel

Name of the cross-validated model, a string.

Kfold

Number of folds used in a cross-validated ensemble, a positive integer.

ModelParams

Object holding parameters of `cvens`.

NObservations

Number of data points used in training the ensemble, a positive integer.

NTrainedPerFold

Number of data points used in training each fold of the ensemble, a positive integer.

Partition

Partition of class `cvpartition` used in creating the cross-validated ensemble.

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in `X`.

Prior

ClassificationPartitionedEnsemble

Prior probabilities for each class. `Prior` is a numeric vector whose entries relate to the corresponding `ClassNames` property.

ResponseName

Name of the response variable `Y`, a string.

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$. For a list of built-in transformation functions and the syntax of custom transformation functions, see `ClassificationTree.fit`.

Add or change a `ScoreTransform` function by dot addressing:

```
ens.ScoreTransform = 'function'
```

or

```
ens.ScoreTransform = @function
```

Trainable

Cell array of ensembles trained on cross-validation folds. Every ensemble is full, meaning it contains its training data and weights.

Trained

Cell array of compact ensembles trained on cross-validation folds.

W

Scaled `weights`, a vector with length `n`, the number of rows in `X`.

X

A matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

Y

A numeric column vector with the same number of rows as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

Methods

kfoldEdge	Classification edge for observations not used for training
kfoldLoss	Classification loss for observations not used for training
resume	Resume training learners on cross-validation folds

Inherited Methods

kfoldEdge	Classification edge for observations not used for training
kfoldfun	Cross validate function
kfoldLoss	Classification loss for observations not used for training
kfoldMargin	Classification margins for observations not used for training
kfoldPredict	Predict response for observations not used for training

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Evaluate the k-fold cross-validation error for a classification ensemble that models the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
cvens = crossval(ens);
L = kfoldLoss(cvens)
```

ClassificationPartitionedEnsemble

L =
0.0533

See Also

[RegressionPartitionedEnsemble](#) |
[ClassificationPartitionedModel](#) | [ClassificationEnsemble](#)

Purpose

Cross-validated classification model

Description

`ClassificationPartitionedModel` is a set of classification models trained on cross-validated folds. Estimate the quality of classification by cross validation using one or more “kfold” methods: `kfoldPredict`, `kfoldLoss`, `kfoldMargin`, `kfoldEdge`, and `kfoldfun`.

Every “kfold” method uses models trained on in-fold observations to predict response for out-of-fold observations. For example, suppose you cross validate using five folds. In this case, every training fold contains roughly 4/5 of the data and every test fold contains roughly 1/5 of the data. The first model stored in `Trained{1}` was trained on `X` and `Y` with the first 1/5 excluded, the second model stored in `Trained{2}` was trained on `X` and `Y` with the second 1/5 excluded, and so on. When you call `kfoldPredict`, it computes predictions for the first 1/5 of the data using the first model, for the second 1/5 of data using the second model, and so on. In short, response for every observation is computed by `kfoldPredict` using the model trained without this observation.

Construction

`cvmodel = crossval(obj)` creates a cross-validated classification model from a classification model.

`cvmodel = ClassificationTree.fit(X,Y,name,value)` or `cvmodel = ClassificationDiscriminant.fit(X,Y,name,value)` creates a cross-validated model when `name` is one of 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'. For syntax details, see the `ClassificationTree.fit` or `ClassificationDiscriminant.fit` function reference pages.

Input Arguments

obj

A classification model. `obj` can be a classification tree constructed using `ClassificationTree.fit`, or a discriminant analysis classifier constructed using `ClassificationDiscriminant.fit`.

ClassificationPartitionedModel

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.

ClassNames

List of the elements in `Y` with duplicates removed. `ClassNames` can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. `ClassNames` has the same data type as the data in the argument `Y`.

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class `j` if its true class is `i`.

If `cvmodel` is a cross-validated `ClassificationDiscriminant` model, you can change a `Cost` matrix by dot addressing:

```
cvmodel.Cost = costMatrix
```

CrossValidatedModel

Name of the cross-validated model, a string.

Kfold

Number of folds used in cross-validated model, a positive integer.

ModelParams

Object holding parameters of `cvmodel`.

Partition

The partition of class `cvpartition` used in creating the cross-validated model.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

Prior

Prior probabilities for each class. Prior is a numeric vector whose entries relate to the corresponding ClassNames property.

If cvmodel is a cross-validated ClassificationDiscriminant model, you can change a Prior vector by dot addressing:

```
cvmodel.Prior = priorVector
```

ResponseName

Name of the response variable Y, a string.

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function.

String	Formula
'symmetric'	$2x - 1$
'invlogit'	$\log(x / (1-x))$
'ismax'	Set score for the class with the largest score to 1, and scores for all other classes to 0.
'symmetricismax'	Set score for the class with the largest score to 1, and scores for all other classes to -1.
'none'	x
'logit'	$1/(1 + e^{-x})$
'doublelogit'	$1/(1 + e^{-2x})$
'symmetriclogit'	$2/(1 + e^{-x}) - 1$
'sign'	-1 for $x < 0$ 0 for $x = 0$ 1 for $x > 0$

ClassificationPartitionedModel

You can include your own function handle for transforming scores. Your function should accept a matrix (the original scores) and return a matrix of the same size (the transformed scores).

Add or change a ScoreTransform function by dot addressing:

```
cvmodel.ScoreTransform = 'function'  
or  
cvmodel.ScoreTransform = @function
```

Trained

The trained learners, a cell array of compact classification models.

W

The scaled **weights**, a vector with length n , the number of rows in X .

X

A matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

Y

A numeric column vector with the same number of rows as X . Each entry in Y is the response to the data in the corresponding row of X .

Methods

kfoldEdge	Classification edge for observations not used for training
kfoldfun	Cross validate function
kfoldLoss	Classification loss for observations not used for training

kfoldMargin	Classification margins for observations not used for training
kfoldPredict	Predict response for observations not used for training

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Evaluate the k-fold cross-validation error for a classification tree model of the Fisher iris data:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
cvtree = crossval(tree);
L = kfoldLoss(cvtree)
```

```
L =
    0.0600
```

See Also

ClassificationPartitionedEnsemble |
RegressionPartitionedModel

How To

- “Example: Cross Validating a Discriminant Analysis Classifier” on page 12-18

ClassificationTree

Superclasses CompactClassificationTree

Purpose Binary decision tree for classification

Description A decision tree with binary splits for classification. An object of class `ClassificationTree` can predict responses for new data with the `predict` method. The object contains the data used for training, so can compute resubstitution predictions.

Construction `tree = ClassificationTree.fit(X,Y)` returns a classification tree based on the input variables (also known as predictors, features, or attributes) `X` and output (response) `Y`. `tree` is a binary tree, where each branching node is split based on the values of a column of `X`.

`tree = ClassificationTree.fit(X,Y,Name,Value)` fits a tree with additional options specified by one or more `Name,Value` pair arguments. If you use one of the following five options, `tree` is of class `ClassificationPartitionedModel`: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Otherwise, `tree` is of class `ClassificationTree`.

Input Arguments

X

A matrix of numeric predictor values. Each column of `X` represents one variable, and each row represents one observation.

NaN values in `X` are taken to be missing values. Observations with all missing values for `X` are not used in the fit. Observations with some missing values for `X` are used to find splits on variables for which these observations have valid values.

Y

A numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of `Y` represents the classification of the corresponding

row of X . For numeric Y , consider using `RegressionTree.fit` instead of `ClassificationTree.fit`.

NaN values in Y are taken to be missing values. Observations with missing values for Y are not used in the fit.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

CategoricalPredictors

List of categorical predictors. Pass `CategoricalPredictors` as one of:

- A numeric vector with indices from 1 to p , where p is the number of columns of X .
- A logical vector of length p , where a `true` entry means that the corresponding column of X is a categorical variable.
- `'all'`, meaning all predictors are categorical.
- A cell array of strings, where each element in the array is the name of a predictor variable. The names must match entries in `PredictorNames` values.
- A character matrix, where each row of the matrix is a name of a predictor variable. The names must match entries in `PredictorNames` values. Pad the names with extra blanks so each row of the character matrix has the same length.

Default: []

ClassNames

Array of class names. Use the data type that exists in Y .

ClassificationTree

Use `ClassNames` to order the classes or to select a subset of classes for training.

Default: The class names that exist in `Y`

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class `j` if its true class is `i`. Alternatively, `Cost` can be a structure `S` having two fields: `S.ClassNames` containing the group names as a variable of the same type as `Y`, and `S.ClassificationCosts` containing the cost matrix.

Default: `Cost(i, j)=1` if `i≠j`, and `Cost(i, j)=0` if `i=j`

crossval

If `'on'`, grows a cross-validated decision tree with 10 folds. You can use `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'` parameters to override this cross-validation setting. You can only use one of these four parameters (`'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`) at a time when creating a cross-validated tree.

Alternatively, cross validate `tree` later using the `crossval` method.

Default: `'off'`

cvpartition

Partition created with `cvpartition` to use in a cross-validated tree. You can only use one of these four options at a time for creating a cross-validated tree: `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`.

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar

from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

MergeLeaves

When 'on', `ClassificationTree.fit` merges leaves that originate from the same parent node, and that give a sum of risk values greater or equal to the risk associated with the parent node. When 'off', `ClassificationTree.fit` does not merge leaves.

Default: 'on'

MinLeaf

Each leaf has at least `MinLeaf` observations per tree leaf. If you supply both `MinParent` and `MinLeaf`, `ClassificationTree.fit` uses the setting that gives larger leaves: `MinParent=max(MinParent,2*MinLeaf)`.

Default: 1

MinParent

ClassificationTree

Each branch node in the tree has at least `MinParent` observations. If you supply both `MinParent` and `MinLeaf`, `ClassificationTree.fit` uses the setting that gives larger leaves: `MinParent=max(MinParent,2*MinLeaf)`.

Default: 10

NVarToSample

Number of predictors to select at random for each split. Can be a positive integer or 'all', which means use all available predictors.

Default: 'all'

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

Default: {'x1', 'x2', ...}

prior

Prior probabilities for each class. Specify as one of:

- A string:
 - 'empirical' determines class probabilities from class frequencies in `Y`. If you pass observation weights, they are used to compute the class probabilities.
 - 'uniform' sets all class probabilities equal.
- A vector (one scalar value for each class)
- A structure `S` with two fields:
 - `S.ClassNames` containing the class names as a variable of the same type as `Y`

- `S.ClassProbs` containing a vector of corresponding probabilities

If you set values for both `weights` and `prior`, the weights are renormalized to add up to the value of the prior probability in the respective class.

Default: 'empirical'

Prune

When 'on', `ClassificationTree.fit` grows the classification tree, and computes the optimal sequence of pruned subtrees. When 'off' `ClassificationTree.fit` grows the classification tree without pruning.

Default: 'on'

PruneCriterion

String with the pruning criterion, either 'error' or 'impurity'.

Default: 'error'

ResponseName

Name of the response variable Y , a string.

Default: 'Response'

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function.

String	Formula
'symmetric'	$2x - 1$
'invlogit'	$\log(x / (1-x))$

ClassificationTree

String	Formula
'ismax'	Set score for the class with the largest score to 1, and scores for all other classes to 0.
'symmetricismax'	Set score for the class with the largest score to 1, and scores for all other classes to -1.
'none'	x
'logit'	$1/(1 + e^{-x})$
'doublelogit'	$1/(1 + e^{-2x})$
'symmetriclogit'	$2/(1 + e^{-x}) - 1$
'sign'	-1 for $x < 0$ 0 for $x = 0$ 1 for $x > 0$

You can include your own function handle for transforming scores. Your function should accept a matrix (the original scores) and return a matrix of the same size (the transformed scores).

Default: 'none'

SplitCriterion

Criterion for choosing a split. One of 'gdi' (Gini's diversity index), 'twoing' for the twoing rule, or 'deviance' for maximum deviance reduction (also known as cross entropy).

Default: 'gdi'

Surrogate

When 'on', `ClassificationTree.fit` finds surrogate splits at each branch node. This setting improves the accuracy of predictions for data with missing values. The setting also enables

you to compute measures of predictive association between predictors. This setting can use much time and memory.

Default: 'off'

weights

Vector of observation weights. The length of `weights` is the number of rows in `X`. `ClassificationTree.fit` normalizes the weights in each class to add up to the value of the prior probability of the class.

Default: `ones(size(X,1),1)`

Properties

CategoricalPredictors

List of categorical predictors, a numeric vector with indices from 1 to p , where p is the number of columns of `X`.

CatSplit

An n -by-2 cell array, where n is the number of categorical splits in `tree`. Each row in `CatSplit` gives left and right values for a categorical split. For each branch node with categorical split j based on a categorical predictor variable z , the left child is chosen if z is in `CatSplit(j,1)` and the right child is chosen if z is in `CatSplit(j,2)`. The splits are in the same order as nodes of the tree. Find the nodes for these splits by selecting 'categorical' cuts from top to bottom in the `CutType` property.

Children

An n -by-2 array containing the numbers of the child nodes for each node in `tree`, where n is the number of nodes. Leaf nodes have child node 0.

ClassCount

An n -by- k array of class counts for the nodes in `tree`, where n is the number of nodes and k is the number of classes. For any node number i , the class counts `ClassCount(i,:)` are counts of

ClassificationTree

observations (from the data used in fitting the tree) from each class satisfying the conditions for node i .

ClassNames

List of the elements in Y with duplicates removed. **ClassNames** can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. **ClassNames** has the same data type as the data in the argument Y .

ClassProb

An n -by- k array of class probabilities for the nodes in **tree**, where n is the number of nodes and k is the number of classes. For any node number i , the class probabilities **ClassProb**($i, :$) are the estimated probabilities for each class for a point satisfying the conditions for node i .

Cost

Square matrix, where **Cost**(i, j) is the cost of classifying a point into class j if its true class is i .

CutCategories

An n -by-2 cell array of the categories used at branches in **tree**, where n is the number of nodes. For each branch node i based on a categorical predictor variable x , the left child is chosen if x is among the categories listed in **CutCategories**{ $i, 1$ }, and the right child is chosen if x is among those listed in **CutCategories**{ $i, 2$ }. Both columns of **CutCategories** are empty for branch nodes based on continuous predictors and for leaf nodes.

CutPoint contains the cut points for 'continuous' cuts, and **CutCategories** contains the set of categories.

CutPoint

An n -element vector of the values used as cut points in **tree**, where n is the number of nodes. For each branch node i based on a continuous predictor variable x , the left child is chosen if $x < \text{CutPoint}(i)$ and the right child is chosen if $x \geq \text{CutPoint}(i)$.

CutPoint is NaN for branch nodes based on categorical predictors and for leaf nodes.

CutPoint contains the cut points for 'continuous' cuts, and CutCategories contains the set of categories.

CutType

An n -element cell array indicating the type of cut at each node in `tree`, where n is the number of nodes. For each node i , `CutType{i}` is:

- 'continuous' — If the cut is defined in the form $x < v$ for a variable x and cut point v .
- 'categorical' — If the cut is defined by whether a variable x takes a value in a set of categories.
- '' — If i is a leaf node.

CutPoint contains the cut points for 'continuous' cuts, and CutCategories contains the set of categories.

CutVar

An n -element cell array of the names of the variables used for branching in each node in `tree`, where n is the number of nodes. These variables are sometimes known as *cut variables*. For leaf nodes, `CutVar` contains an empty string.

CutPoint contains the cut points for 'continuous' cuts, and CutCategories contains the set of categories.

IsBranch

An n -element logical vector that is true for each branch node and false for each leaf node of `tree`.

ModelParams

Parameters used in training `tree`.

NObservations

ClassificationTree

Number of observations in the training data, a numeric scalar. `NObservations` can be less than the number of rows of input data `X` when there are missing values in `X` or response `Y`.

NodeClass

An n -element cell array with the names of the most probable classes in each node of `tree`, where n is the number of nodes in the tree. Every element of this array is a string equal to one of the class names in `ClassNames`.

NodeErr

An n -element vector of the errors of the nodes in `tree`, where n is the number of nodes. `NodeErr(i)` is the misclassification probability for node i .

NodeProb

An n -element vector of the probabilities of the nodes in `tree`, where n is the number of nodes. The probability of a node is computed as the proportion of observations from the original data that satisfy the conditions for the node. This proportion is adjusted for any prior probabilities assigned to each class.

NodeSize

An n -element vector of the sizes of the nodes in `tree`, where n is the number of nodes. The size of a node is defined as the number of observations from the data used to create the tree that satisfy the conditions for the node.

NumNodes

The number of nodes in `tree`.

Parent

An n -element vector containing the number of the parent node for each node in `tree`, where n is the number of nodes. The parent of the root node is 0.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

Prior

Prior probabilities for each class. `Prior` is a numeric vector whose entries relate to the corresponding `ClassNames` property.

PruneList

An n -element numeric vector with the pruning levels in each node of `tree`, where n is the number of nodes.

ResponseName

String describing the response variable `Y`.

Risk

An n -element vector of the risk of the nodes in `tree`, where n is the number of nodes.

- If `tree` was grown with `SplitCriterion` set to either `'gdi'` (default) or `'deviance'`, then the risk at node `i` is the impurity of node `i` times the node probability. See “Definitions” on page 20-240.
- Otherwise,

$$\text{Risk}(i) = \text{NodeErr}(i) * \text{NodeProb}(i).$$

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. `'none'` means no transformation; equivalently, `'none'` means `@(x)x`.

Add or change a `ScoreTransform` function by dot addressing:

```
tree.ScoreTransform = 'function'  
or  
tree.ScoreTransform = @function
```

SurrCutCategories

An n -element cell array of the categories used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutCategories{k}` is a cell array. The length of `SurrCutCategories{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutCategories{k}` is either an empty string for a continuous surrogate predictor, or is a two-element cell array with categories for a categorical surrogate predictor. The first element of this two-element cell array lists categories assigned to the left child by this surrogate split, and the second element of this two-element cell array lists categories assigned to the right child by this surrogate split. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutCategories` contains an empty cell.

SurrCutFlip

An n -element cell array of the numeric cut assignments used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutFlip{k}` is a numeric vector. The length of `SurrCutFlip{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutFlip{k}` is either zero for a categorical surrogate predictor, or a numeric cut assignment for a continuous surrogate predictor. The numeric cut assignment can be either -1 or $+1$. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and the cut assignment for this surrogate split is $+1$, or if $Z \geq C$ and the cut assignment for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and the cut assignment for this surrogate split is $+1$, or if $Z < C$ and the cut assignment for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutFlip` contains an empty array.

SurrCutPoint

An n -element cell array of the numeric values used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutPoint{k}` is a numeric vector. The length of `SurrCutPoint{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutPoint{k}` is either NaN for a categorical surrogate predictor, or a numeric cut for a continuous surrogate predictor. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and `SurrCutFlip` for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and `SurrCutFlip` for this surrogate split is $+1$, or if $Z < C$ and `SurrCutFlip` for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables returned by `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutPoint` contains an empty cell.

SurrCutType

An n -element cell array indicating types of surrogate splits at each node in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutType{k}` is a cell array with the types of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutType` contains an empty cell. A surrogate split type can be either 'continuous' if the cut is defined in the form $Z < V$ for a variable Z and cut point V or 'categorical' if the cut is defined by whether Z takes a value in a set of categories.

SurrCutVar

An n -element cell array of the names of the variables used for surrogate splits in each node in `tree`, where n is the number of nodes in `tree`. Every element of `SurrCutVar` is a cell array with the names of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutVar` contains an empty cell.

SurrVarAssoc

An n -element cell array of the predictive measures of association for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrVarAssoc{k}` is a numeric vector. The length of `SurrVarAssoc{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrVarAssoc{k}` gives the predictive measure of association between the optimal split and this surrogate split. The order of the surrogate split variables at each node is the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrVarAssoc` contains an empty cell.

W

The scaled **weights**, a vector with length n , the number of rows in `X`.

X

A matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

Y

A numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of `Y` represents the classification of the corresponding row of `X`.

Methods

<code>compact</code>	Compact tree
<code>crossval</code>	Cross-validated decision tree
<code>cvloss</code>	Classification error by cross validation
<code>fit</code>	Fit classification tree
<code>prune</code>	Produce sequence of subtrees by pruning
<code>resubEdge</code>	Classification edge by resubstitution
<code>resubLoss</code>	Classification error by resubstitution
<code>resubMargin</code>	Classification margins by resubstitution
<code>resubPredict</code>	Predict resubstitution response of tree
<code>template</code>	Create classification template

Inherited Methods

<code>edge</code>	Classification edge
<code>loss</code>	Classification error
<code>margin</code>	Classification margins
<code>meanSurrVarAssoc</code>	Mean predictive measure of association for surrogate splits in decision tree
<code>predict</code>	Predict classification
<code>predictorImportance</code>	Estimates of predictor importance
<code>view</code>	View tree

Definitions Impurity and Node Error

ClassificationTree splits nodes based on either *impurity* or *node error*. Impurity means one of several things, depending on your choice of the SplitCriterion name-value pair:

- Gini's Diversity Index (`gdi`) — The Gini index of a node is

$$1 - \sum_i p^2(i),$$

where the sum is over the classes i at the node, and $p(i)$ is the observed fraction of classes with class i that reach the node. A node with just one class (a *pure* node) has Gini index 0; otherwise the Gini index is positive. So the Gini index is a measure of node impurity.

- Deviance ('`deviance`') — With $p(i)$ defined as for the Gini index, the deviance of a node is

$$-\sum_i p(i) \log p(i).$$

A pure node has deviance 0; otherwise, the deviance is positive.

- Twoing rule ('`twoing`') — Twoing is not a purity measure of a node, but is a different measure for deciding how to split a node. Let $L(i)$ denote the fraction of members of class i in the left child node after a split, and $R(i)$ denote the fraction of members of class i in the right child node after a split. Choose the split criterion to maximize

$$P(L)P(R) \left(\sum_i |L(i) - R(i)| \right)^2,$$

where $P(L)$ and $P(R)$ are the fractions of observations that split to the left and right respectively. If the expression is large, the split made each child node purer. Similarly, if the expression is small, the split made each child node similar to each other, and hence similar to the parent node, and so the split did not increase node purity.

- Node error — The node error is the fraction of misclassified classes at a node. If j is the class with largest number of training samples at a node, the node error is

$$1 - p(j).$$

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Construct a classification tree for the data in `ionosphere.mat`:

```
load ionosphere
tc = ClassificationTree.fit(X,Y)

tc =

ClassificationTree:
    PredictorNames: {1x34 cell}
    CategoricalPredictors: []
    ResponseName: 'Response'
    ClassNames: {'b' 'g'}
    Cost: [2x2 double]
    Prior: [0.3590 0.6410]
    ScoreTransform: 'none'
    X: [351x34 double]
    Y: {351x1 cell}
    W: [351x1 double]
    ModelParams: [1x1 classreg.learning.modelparams.TreeParams]
```

See Also

[RegressionTree](#) | [ClassificationEnsemble](#) | [ClassificationTree.fit](#) | [CompactClassificationTree](#) | [predict](#)

How To

- “Classification Trees and Regression Trees” on page 13-30

classify

Purpose

Discriminant analysis

Syntax

```
class = classify(sample,training,group)
class = classify(sample,training,group,'type')
class = classify(sample,training,group,'type',prior)
[class,err] = classify(...)
[class,err,POSTERIOR] = classify(...)
[class,err,POSTERIOR,logp] = classify(...)
[class,err,POSTERIOR,logp,coeff] = classify(...)
```

Description

`class = classify(sample,training,group)` classifies each row of the data in `sample` into one of the groups in `training`. `sample` and `training` must be matrices with the same number of columns. `group` is a grouping variable for `training`. Its unique values define groups; each element defines the group to which the corresponding row of `training` belongs. `group` can be a categorical variable, a numeric vector, a string array, or a cell array of strings. `training` and `group` must have the same number of rows. `classify` treats NaNs or empty strings in `group` as missing values, and ignores the corresponding rows of `training`. The output `class` indicates the group to which each row of `sample` has been assigned, and is of the same type as `group`.

`class = classify(sample,training,group,'type')` allows you to specify the type of discriminant function. Specify `type` inside single quotes. `type` is one of:

- `linear` — Fits a multivariate normal density to each group, with a pooled estimate of covariance. This is the default.
- `diaglinear` — Similar to `linear`, but with a diagonal covariance matrix estimate (naive Bayes classifiers).
- `quadratic` — Fits multivariate normal densities with covariance estimates stratified by group.
- `diagquadratic` — Similar to `quadratic`, but with a diagonal covariance matrix estimate (naive Bayes classifiers).
- `mahalanobis` — Uses Mahalanobis distances with stratified covariance estimates.

`class = classify(sample, training, group, 'type', prior)` allows you to specify prior probabilities for the groups. *prior* is one of:

- A numeric vector the same length as the number of unique values in `group` (or the number of levels defined for `group`, if `group` is categorical). If `group` is numeric or categorical, the order of *prior* must correspond to the ordered values in `group`, or, if `group` contains strings, to the order of first occurrence of the values in `group`.
- A 1-by-1 structure with fields:
 - `prob` — A numeric vector.
 - `group` — Of the same type as `group`, containing unique values indicating the groups to which the elements of `prob` correspond.

As a structure, *prior* can contain groups that do not appear in `group`. This can be useful if `training` is a subset a larger training set. `classify` ignores any groups that appear in the structure but not in the `group` array.

- The string 'empirical', indicating that group prior probabilities should be estimated from the group relative frequencies in `training`.

prior defaults to a numeric vector of equal probabilities, i.e., a uniform distribution. *prior* is not used for discrimination by Mahalanobis distance, except for error rate calculation.

`[class, err] = classify(...)` also returns an estimate `err` of the misclassification error rate based on the `training` data. `classify` returns the apparent error rate, i.e., the percentage of observations in `training` that are misclassified, weighted by the prior probabilities for the groups.

`[class, err, POSTERIOR] = classify(...)` also returns a matrix `POSTERIOR` of estimates of the posterior probabilities that the *j*th training group was the source of the *i*th sample observation, i.e., $Pr(\text{group } j | \text{obs } i)$. `POSTERIOR` is not computed for Mahalanobis discrimination.

`[class, err, POSTERIOR, logp] = classify(...)` also returns a vector `logp` containing estimates of the logarithms of the unconditional

classify

predictive probability density of the sample observations, $p(\text{obs } i) = \sum p(\text{obs } i | \text{group } j) Pr(\text{group } j)$ over all groups. `logp` is not computed for Mahalanobis discrimination.

`[class,err,POSTERIOR,logp,coeff] = classify(...)` also returns a structure array `coeff` containing coefficients of the boundary curves between pairs of groups. Each element `coeff(I,J)` contains information for comparing group I to group J in the following fields:

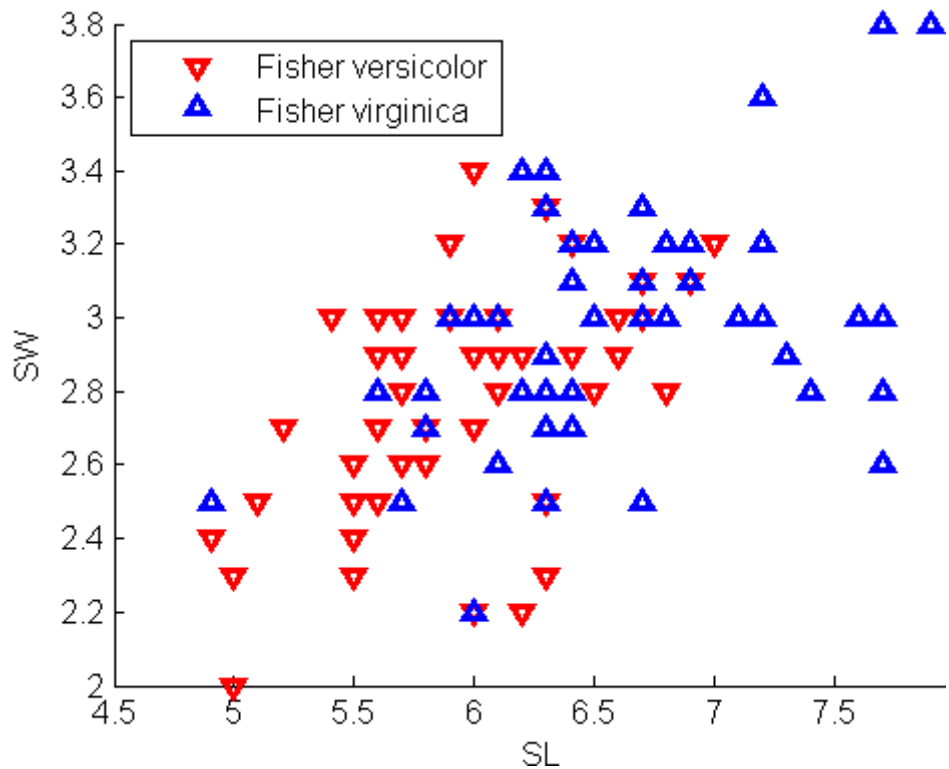
- `type` — Type of discriminant function, from the `type` input.
- `name1` — Name of the first group.
- `name2` — Name of the second group.
- `const` — Constant term of the boundary equation (K)
- `linear` — Linear coefficients of the boundary equation (L)
- `quadratic` — Quadratic coefficient matrix of the boundary equation (Q)

For the `linear` and `diaglinear` types, the quadratic field is absent, and a row `x` from the sample array is classified into group I rather than group J if $0 < K+x*L$. For the other types, `x` is classified into group I if $0 < K+x*L+x*Q*x'$.

Examples

For training data, use Fisher's sepal measurements for iris versicolor and virginica:

```
load fisheriris
SL = meas(51:end,1);
SW = meas(51:end,2);
group = species(51:end);
h1 = gscatter(SL,SW,group, 'rb', 'v^', [], 'off');
set(h1, 'LineWidth', 2)
legend('Fisher versicolor', 'Fisher virginica', ...
       'Location', 'NW')
```



Classify a grid of measurements on the same scale:

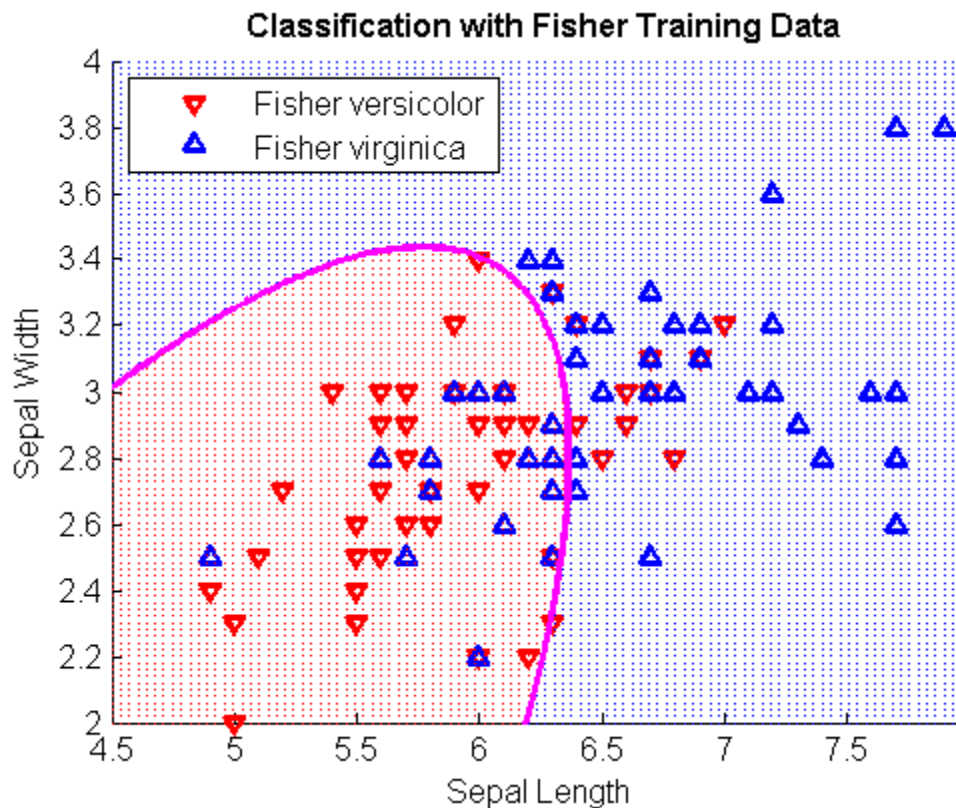
```
[X,Y] = meshgrid(linspace(4.5,8),linspace(2,4));
X = X(:); Y = Y(:);
[C,err,P,logp,coeff] = classify([X Y],[SL SW],...
                                group,'quadratic');
```

Visualize the classification:

```
hold on;
gscatter(X,Y,C,'rb','.',1,'off');
K = coeff(1,2).const;
L = coeff(1,2).linear;
```

classify

```
Q = coeff(1,2).quadratic;  
% Function to compute  $K + L*v + v'*Q*v$  for multiple vectors  
%  $v=[x;y]$ . Accepts x and y as scalars or column vectors.  
f = @(x,y) K + [x y]*L + sum(([x y]*Q) .* [x y], 2);  
  
h2 = ezplot(f,[4.5 8 2 4]);  
set(h2,'Color','m','LineWidth',2)  
axis([4.5 8 2 4])  
xlabel('Sepal Length')  
ylabel('Sepal Width')  
title('\bf Classification with Fisher Training Data')
```



References

[1] Krzanowski, W. J. *Principles of Multivariate Analysis: A User's Perspective*. New York: Oxford University Press, 1988.

[2] Seber, G. A. F. *Multivariate Observations*. Hoboken, NJ: John Wiley & Sons, Inc., 1984.

See Also

`classregtree` | `mahal` | `NaiveBayes`

How To

- “Grouping Variables” on page 2-72

classregtree.classname

Purpose Class names for classification decision tree

Syntax CNames = classname(T)
 CNames = classname(T,J)

Description CNames = classname(T) returns a cell array of strings with class names for this classification decision tree.

 CNames = classname(T,J) takes an array J of class numbers and returns the class names for the specified numbers.

See Also classregtree

TreeBagger.ClassNames property

Purpose Names of classes

Description The `ClassNames` property is a cell array containing the class names for the response variable Y . This property is empty for regression trees.

classregtree.classprob

Purpose Class probabilities

Syntax `P = classprob(t)`
`P = classprob(t,nodes)`

Description `P = classprob(t)` returns an n -by- m array P of class probabilities for the nodes in the classification tree t , where n is the number of nodes and m is the number of classes. For any node number i , the class probabilities $P(i,:)$ are the estimated probabilities for each class for a point satisfying the conditions for node i .

`P = classprob(t,nodes)` takes a vector `nodes` of node numbers and returns the class probabilities for the specified nodes.

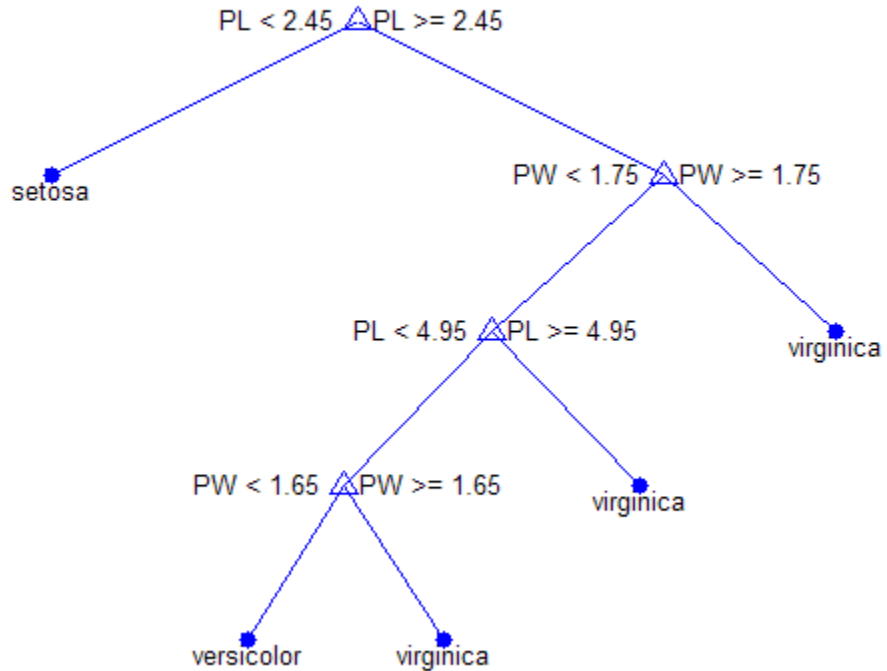
Examples Create a classification tree for Fisher's iris data:

```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

Click to display: Magnification: Pruning level:



P = classprob(t)

P =

0.3333	0.3333	0.3333
1.0000	0	0
0	0.5000	0.5000
0	0.9074	0.0926
0	0.0217	0.9783
0	0.9792	0.0208
0	0.3333	0.6667
0	1.0000	0

classregtree.classprob

0 0 1.0000

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree | numnodes

Purpose	Classification and regression trees	
Construction	classregtree	Construct classification and regression trees
Methods	catsplit	Categorical splits used for branches in decision tree
	children	Child nodes
	classcount	Class counts
	classname	Class names for classification decision tree
	classprob	Class probabilities
	cutcategories	Cut categories
	cutpoint	Decision tree cut point values
	cuttype	Cut types
	cutvar	Cut variable names
	disp	Display classregtree object
	display	Display classregtree object
	eval	Predicted responses
	isbranch	Test node for branch
	meansurrvarassoc	Mean predictive measure of association for surrogate splits in decision tree
	nodeclass	Class values of nodes of classification tree
	nodeerr	Return vector of node errors

classregtree

nodemean	Mean values of nodes of regression tree
nodeprob	Node probabilities
nodesize	Return node size
numnodes	Number of nodes
parent	Parent node
prune	Prune tree
prunelist	Pruning levels for decision tree nodes
risk	Node risks
subsasgn	Subscripted reference for classregtree object
suboref	Subscripted reference for classregtree object
surrucutcategories	Categories used for surrogate splits in decision tree
surrucutflip	Numeric cutpoint assignments used for surrogate splits in decision tree
surrucutpoint	Cutpoints used for surrogate splits in decision tree
surrucuttype	Types of surrogate splits used at branches in decision tree
surrucutvar	Variables used for surrogate splits in decision tree
surrvarassoc	Predictive measure of association for surrogate splits in decision tree
test	Error rate

type	Tree type
varimportance	Compute embedded estimates of input feature importance
view	Plot tree

Properties

Objects of the `classregtree` class have no properties accessible by dot indexing, `get` methods, or `set` methods. To obtain information about a `classregtree` object, use the appropriate method.

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

How To

- “Ensemble Methods” on page 13-54
- “Classification Trees and Regression Trees” on page 13-30
- “Grouping Variables” on page 2-72

classregtree

Purpose Construct classification and regression trees

Syntax
`t = classregtree(X,y)`
`t = classregtree(X,y,'Name',value)`

Description `t = classregtree(X,y)` creates a decision tree `t` for predicting the response `y` as a function of the predictors in the columns of `X`. `X` is an n -by- m matrix of predictor values. If `y` is a vector of n response values, `classregtree` performs regression. If `y` is a categorical variable, character array, or cell array of strings, `classregtree` performs classification. Either way, `t` is a binary tree where each branching node is split based on the values of a column of `X`. NaN values in `X` or `y` are taken to be missing values. Observations with all missing values for `X` or missing values for `y` are not used in the fit. Observations with some missing values for `X` are used to find splits on variables for which these observations have valid values.

`t = classregtree(X,y,'Name',value)` specifies one or more optional parameter name/value pairs. Specify *Name* in single quotes. The following options are available:

For all trees:

- `categorical` — Vector of indices of the columns of X that are to be treated as unordered categorical variables
- `method` — Either 'classification' (default if y is text or a categorical variable) or 'regression' (default if y is numeric).
- `names` — A cell array of names for the predictor variables, in the order in which they appear in the X from which the tree was created.
- `prune` — 'on' (default) to compute the full tree and the optimal sequence of pruned subtrees, or 'off' for the full tree without pruning.
- `minparent` — A number k such that impure nodes must have k or more observations to be split (default is 10).
- `minleaf` — A minimal number of observations per tree leaf (default is 1). If you supply both 'minparent' and 'minleaf', `classregtree` uses the setting which results in larger leaves: `minparent = max(minparent, 2*minleaf)`
- `mergeleaves` — 'on' (default) to merge leaves that originate from the same parent node and give the sum of risk values greater or equal to the risk associated with the parent node. If 'off', `classregtree` does not merge leaves.
- `nvartosample` — Number of predictor variables randomly selected for each split. By default all variables are considered for each decision split.
- `stream` — Random number stream. Default is the MATLAB default random number stream.
- `surrogate` — 'on' to find surrogate splits at each branch node. Default is 'off'. If you set this parameter to 'on', `classregtree` can run significantly slower and consume significantly more memory.
- `weights` — Vector of observation weights. By default the weight of every observation is 1. The length of this vector must be equal to the number of rows in X .

For regression trees only:

- `qetoler` — Defines tolerance on quadratic error per node for regression trees. Splitting nodes stops when quadratic error per node drops below `qetoler*qed`, where `qed` is the quadratic error for the entire data computed before the decision tree is grown: `qed = norm(y-ybar)` with `ybar` estimated as the average of the input array `Y`. Default value is `1e-6`.

For classification trees only:

- `cost` — Square matrix `C`, where `C(i, j)` is the cost of classifying a point into class `j` if its true class is `i` (default has `C(i, j)=1` if `i~j`, and `C(i, j)=0` if `i=j`). Alternatively, this value can be a structure `S` having two fields: `S.group` containing the group names as a categorical variable, character array, or cell array of strings; and `S.cost` containing the cost matrix `C`.
- `splitcriterion` — Criterion for choosing a split. One of `'gdi'` (default) or Gini's diversity index, `'twoing'` for the twoing rule, or `'deviance'` for maximum deviance reduction.
- `priorprob` — Prior probabilities for each class, specified as a string (`'empirical'` or `'equal'`) or as a vector (one value for each distinct group name) or as a structure `S` with two fields:
 - `S.group` containing the group names as a categorical variable, character array, or cell array of strings
 - `S.prob` containing a vector of corresponding probabilities.If the input value is `'empirical'` (default), class probabilities are determined from class frequencies in `Y`. If the input value is `'equal'`, all class probabilities are set equal. If both observation weights and class prior probabilities are supplied, the weights are renormalized to add up to the value of the prior probability in the respective class.

Examples

Create a classification tree for Fisher's iris data:

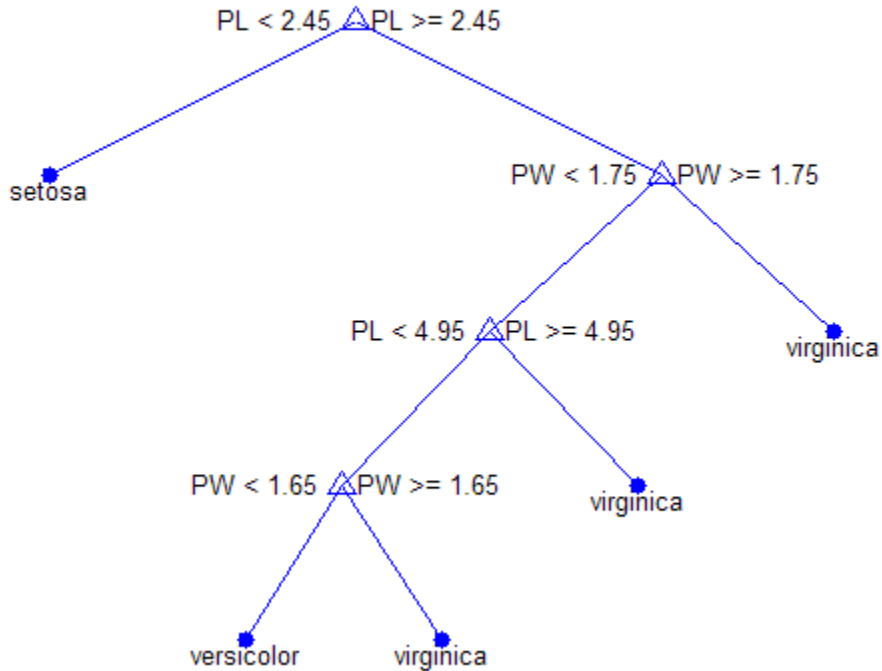
```
load fisheriris;
```

```
t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

classregtree

Click to display: Magnification: Pruning level:



References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

[eval](#) | [prune](#) | [test](#) | [view](#)

How To

- “Grouping Variables” on page 2-72
- “Ensemble Methods” on page 13-54

NaiveBayes.CLevels property

Purpose Class levels

Description The CLevels property is a vector of the same type as the grouping variable, containing the unique levels of the grouping variable.

cluster

Purpose Construct agglomerative clusters from linkages

Syntax

```
T = cluster(Z, 'cutoff', c)
T = cluster(Z, 'cutoff', c, 'depth', d)
T = cluster(Z, 'cutoff', c, 'criterion', criterion)
T = cluster(Z, 'maxclust', n)
```

Description `T = cluster(Z, 'cutoff', c)` constructs clusters from the agglomerative hierarchical cluster tree, `Z`, as generated by the linkage function. `Z` is a matrix of size $(m - 1)$ -by-3, where m is the number of observations in the original data. `c` is a threshold for cutting `Z` into clusters. Clusters are formed when a node and all of its subnodes have inconsistent value less than `c`. All leaves at or below the node are grouped into a cluster. `t` is a vector of size m containing the cluster assignments of each observation.

If `c` is a vector, `T` is a matrix of cluster assignments with one column per cutoff value.

`T = cluster(Z, 'cutoff', c, 'depth', d)` evaluates inconsistent values by looking to a depth `d` below each node. The default depth is 2.

`T = cluster(Z, 'cutoff', c, 'criterion', criterion)` uses the specified criterion for forming clusters, where `criterion` is one of the strings 'inconsistent' (default) or 'distance'. The 'distance' criterion uses the distance between the two subnodes merged at a node to measure node height. All leaves at or below a node with height less than `c` are grouped into a cluster.

`T = cluster(Z, 'maxclust', n)` constructs a maximum of `n` clusters using the 'distance' criterion. `cluster` finds the smallest height at which a horizontal cut through the tree leaves `n` or fewer clusters.

If `n` is a vector, `T` is a matrix of cluster assignments with one column per maximum value.

Examples Compare clusters from Fisher iris data with species:

```
load fisheriris
```



```
d = pdist(meas);  
Z = linkage(d);  
c = cluster(Z, 'maxclust',3:5);
```

```
crosstab(c(:,1),species)
```

```
ans =  
    0    0    2  
    0   50   48  
   50    0    0
```

```
crosstab(c(:,2),species)
```

```
ans =  
    0    0    1  
    0   50   47  
    0    0    2  
   50    0    0
```

```
crosstab(c(:,3),species)
```

```
ans =  
    0    4    0  
    0   46   47  
    0    0    1  
    0    0    2  
   50    0    0
```

See Also

[clusterdata](#) | [cophenet](#) | [inconsistent](#) | [linkage](#) | [pdist](#)

gmdistribution.cluster

Purpose Construct clusters from Gaussian mixture distribution

Syntax

```
idx = cluster(obj,X)
[idx,nlogl] = cluster(obj,X)
[idx,nlogl,P] = cluster(obj,X)
[idx,nlogl,P,logpdf] = cluster(obj,X)
[idx,nlogl,P,logpdf,M] = cluster(obj,X)
```

Description `idx = cluster(obj,X)` partitions data in the n -by- d matrix X , where n is the number of observations and d is the dimension of the data, into k clusters determined by the k components of the Gaussian mixture distribution defined by `obj`. `obj` is an object created by `gmdistribution` or `fit`. `idx` is an n -by-1 vector, where `idx(I)` is the cluster index of observation I . The cluster index gives the component with the largest posterior probability for the observation, weighted by the component probability.

Note The data in X is typically the same as the data used to create the Gaussian mixture distribution defined by `obj`. Clustering with `cluster` is treated as a separate step, apart from density estimation. For `cluster` to provide meaningful clustering with new data, X should come from the same population as the data used to create `obj`.

`cluster` treats NaN values as missing data. Rows of X with NaN values are excluded from the partition.

`[idx,nlogl] = cluster(obj,X)` also returns `nlogl`, the negative log-likelihood of the data.

`[idx,nlogl,P] = cluster(obj,X)` also returns the posterior probabilities of each component for each observation in the n -by- k matrix P . $P(I,J)$ is the probability of component J given observation I .

`[idx,nlogl,P,logpdf] = cluster(obj,X)` also returns the n -by-1 vector `logpdf` containing the logarithm of the estimated probability density function for each observation. The density estimate for

observation I is a sum over all components of the component density at I times the component probability.

`[idx,nlogl,P,logpdf,M] = cluster(obj,X)` also returns an n -by- k matrix M containing Mahalanobis distances in squared units. $M(I,J)$ is the Mahalanobis distance of observation I from the mean of component J .

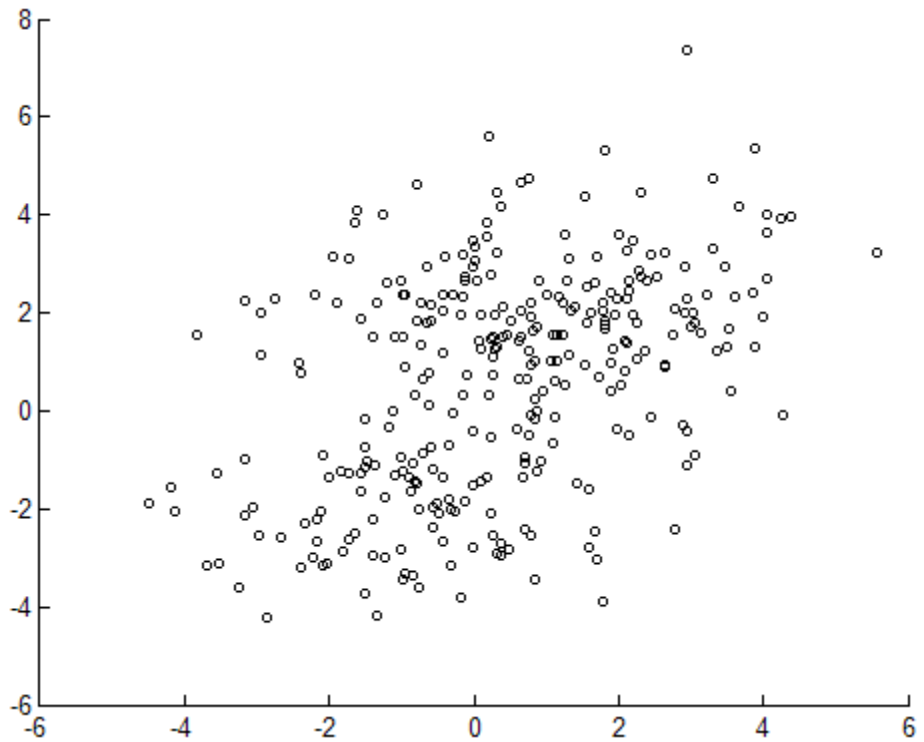
Examples

Generate data from a mixture of two bivariate Gaussian distributions using the `mvnrnd` function:

```
MU1 = [1 2];  
SIGMA1 = [2 0; 0 .5];  
MU2 = [-3 -5];  
SIGMA2 = [1 0; 0 1];  
X = [mvnrnd(MU1,SIGMA1,1000);mvnrnd(MU2,SIGMA2,1000)];
```

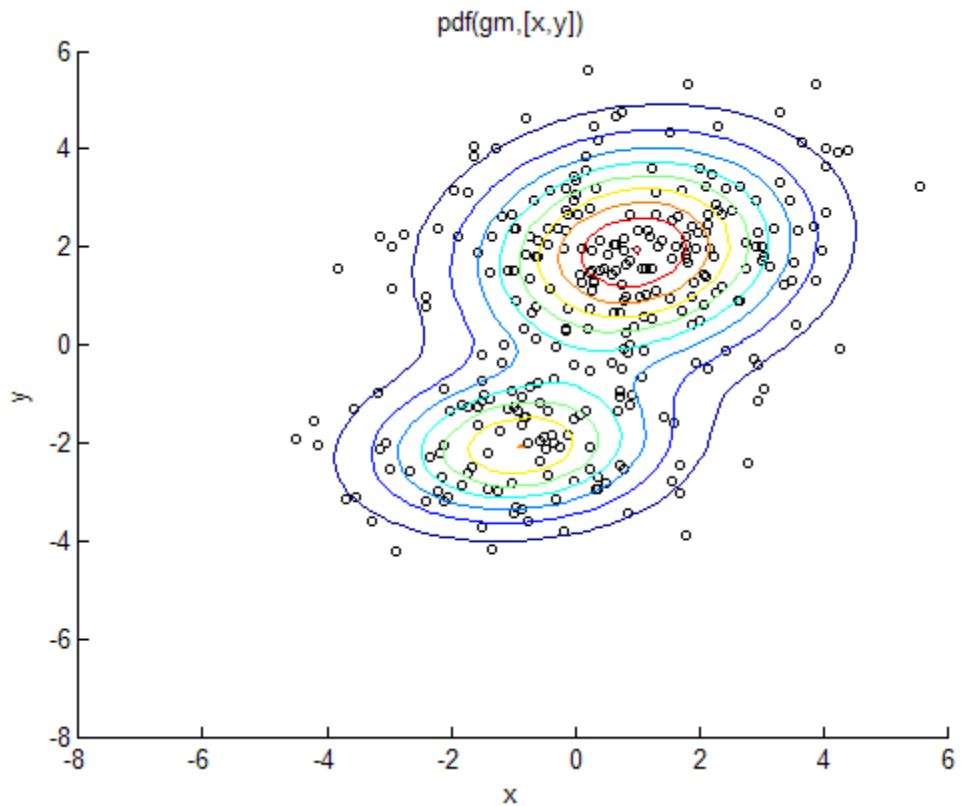
```
scatter(X(:,1),X(:,2),10, ' . ' )  
hold on
```

gmdistribution.cluster



Fit a two-component Gaussian mixture model:

```
obj = gmdistribution.fit(X,2);  
h = ezcontour(@(x,y)pdf(obj,[x y]),[-8 6],[-8 6]);
```



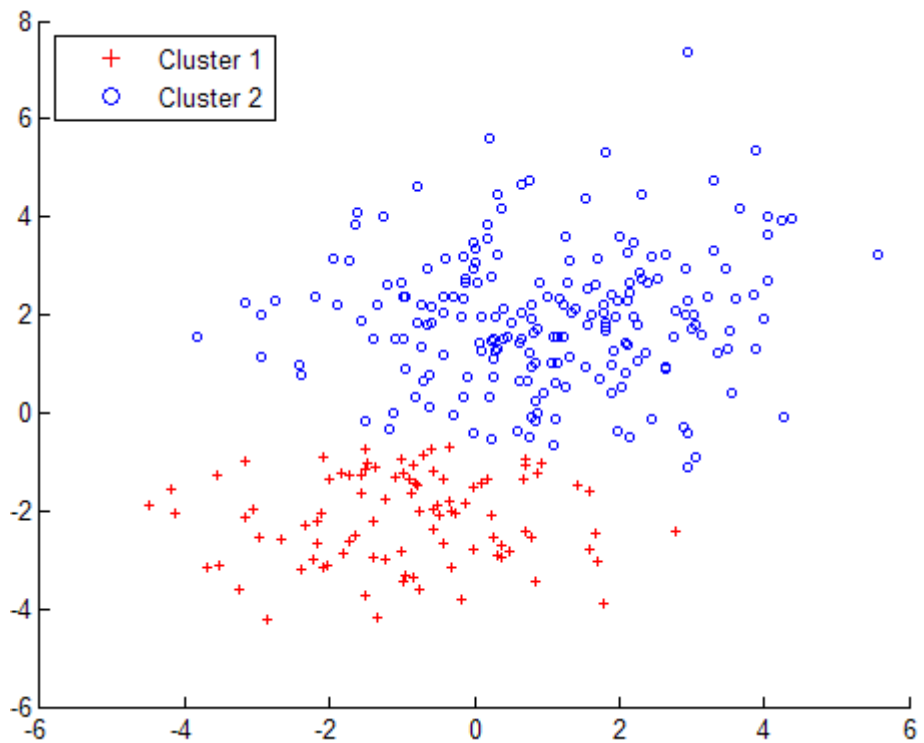
Use the fit to cluster the data:

```
idx = cluster(obj,X);  
cluster1 = X(idx == 1,:);  
cluster2 = X(idx == 2,:);  
  
delete(h)  
h1 = scatter(cluster1(:,1),cluster1(:,2),10,'r.');
```

```
h2 = scatter(cluster2(:,1),cluster2(:,2),10,'g.');
```

```
legend([h1 h2], 'Cluster 1', 'Cluster 2', 'Location', 'NW')
```

gmdistribution.cluster



See Also

`fit` | `gmdistribution` | `mahal` | `posterior`

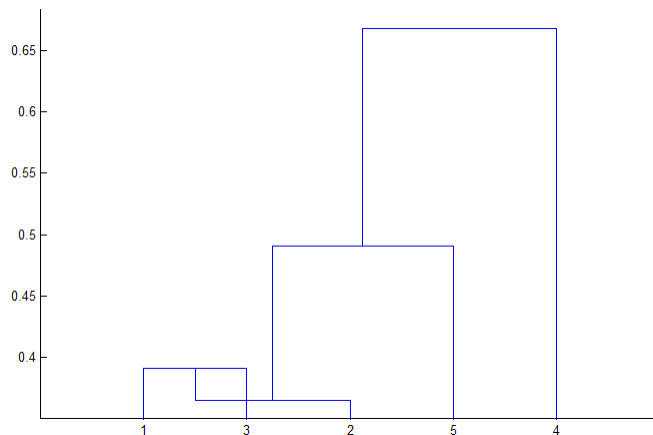
Purpose Agglomerative clusters from data

Syntax
`T = clusterdata(X,cutoff)`
`T = clusterdata(X,Name,Value)`

Description
`T = clusterdata(X,cutoff)`
`T = clusterdata(X,Name,Value)` clusters with additional options specified by one or more `Name,Value` pair arguments.

Tips

- The centroid and median methods can produce a cluster tree that is not monotonic. This occurs when the distance from the union of two clusters, r and s , to a third cluster is less than the distance between r and s . In this case, in a dendrogram drawn with the default orientation, the path from a leaf to the root node takes some downward steps. To avoid this, use another method. The following image shows a nonmonotonic cluster tree.



In this case, cluster 1 and cluster 3 are joined into a new cluster, while the distance between this new cluster and cluster 2 is less than the distance between cluster 1 and cluster 3. This leads to a nonmonotonic tree.

clusterdata

- You can provide the output `T` to other functions including `dendrogram` to display the tree, `cluster` to assign points to clusters, `inconsistent` to compute inconsistent measures, and `cophenet` to compute the cophenetic correlation coefficient.

Input Arguments

X

Matrix with two or more rows. The rows represent observations, the columns represent categories or dimensions.

cutoff

When $0 < \text{cutoff} < 2$, `clusterdata` forms clusters when inconsistent values are greater than `cutoff` (see `inconsistent`). When `cutoff` is an integer ≥ 2 , `clusterdata` interprets `cutoff` as the maximum number of clusters to keep in the hierarchical tree generated by `linkage`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

criterion

Either `'inconsistent'` or `'distance'`.

cutoff

Cutoff for `inconsistent` or `distance` measure, a positive scalar. When $0 < \text{cutoff} < 2$, `clusterdata` forms clusters when inconsistent values are greater than `cutoff` (see `inconsistent`). When `cutoff` is an integer ≥ 2 , `clusterdata` interprets `cutoff` as the maximum number of clusters to keep in the hierarchical tree generated by `linkage`.

depth

Depth for computing inconsistent values, a positive integer.

distance

Any of the distance metric names allowed by `pdist` (follow the 'minkowski' option by the value of the exponent `p`):

Metric	Description
'euclidean'	Euclidean distance (default).
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between rows in <code>X</code> is scaled by dividing by the corresponding element of the standard deviation <code>S=nanstd(X)</code> . To specify another value for <code>S</code> , use <code>D=pdist(X, 'seuclidean', S)</code> .
'cityblock'	City block metric.
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use <code>D = pdist(X, 'minkowski', P)</code> , where <code>P</code> is a scalar
'chebychev'	Chebychev distance (maximum coordinate difference).
'mahalanobis'	Mahalanobis distance, using the sample covariance of <code>X</code> as computed by <code>nancov</code> . To compute the distance with a different covariance, use <code>D = pdist(X, 'mahalanobis', C)</code> , where the matrix <code>C</code> is symmetric and positive definite.
'cosine'	One minus the cosine of the included angle between points (treated as vectors).
'correlation'	One minus the sample correlation between points (treated as sequences of values).
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).

Metric	Description
'hamming'	Hamming distance, which is the percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ.
custom distance function	<p>A distance function specified using @: <code>D = pdist(X,@distfun)</code></p> <p>A distance function must be of form <code>d2 = distfun(XI,XJ)</code></p> <p>taking as arguments a 1-by-<i>n</i> vector <i>XI</i>, corresponding to a single row of <i>X</i>, and an <i>m2</i>-by-<i>n</i> matrix <i>XJ</i>, corresponding to multiple rows of <i>X</i>. <code>distfun</code> must accept a matrix <i>XJ</i> with an arbitrary number of rows. <code>distfun</code> must return an <i>m2</i>-by-1 vector of distances <i>d2</i>, whose <i>k</i>th element is the distance between <i>XI</i> and <i>XJ</i>(<i>k</i>, :).</p>

linkage

Any of the linkage methods allowed by the `linkage` function:

- 'average'
- 'centroid'
- 'complete'
- 'median'
- 'single'
- 'ward'
- 'weighted'

For details, see the definitions in the `linkage` function reference page.

maxclust

Maximum number of clusters to form, a positive integer.

savememory

A string, either 'on' or 'off'. When applicable, the 'on' setting causes clusterdata to construct clusters without computing the distance matrix. savememory is applicable when:

- linkage is 'centroid', 'median', or 'ward'
- distance is 'euclidean' (default)

When savememory is 'on', linkage run time is proportional to the number of dimensions (number of columns of X). When savememory is 'off', linkage memory requirement is proportional to N^2 , where N is the number of observations. So choosing the best (least-time) setting for savememory depends on the problem dimensions, number of observations, and available memory. The default savememory setting is a rough approximation of an optimal setting.

Default: 'on' when X has 20 columns or fewer, or the computer does not have enough memory to store the distance matrix; otherwise 'off'

Output Arguments**T**

T is a vector of size m containing a cluster number for each observation.

- When $0 < \text{cutoff} < 2$, `T = clusterdata(X,cutoff)` is equivalent to:

```
Y = pdist(X,'euclid');
Z = linkage(Y,'single');
T = cluster(Z,'cutoff',cutoff);
```

- When `cutoff` is an integer ≥ 2 , `T = clusterdata(X,cutoff)` is equivalent to:

```
Y = pdist(X,'euclid');
Z = linkage(Y,'single');
```

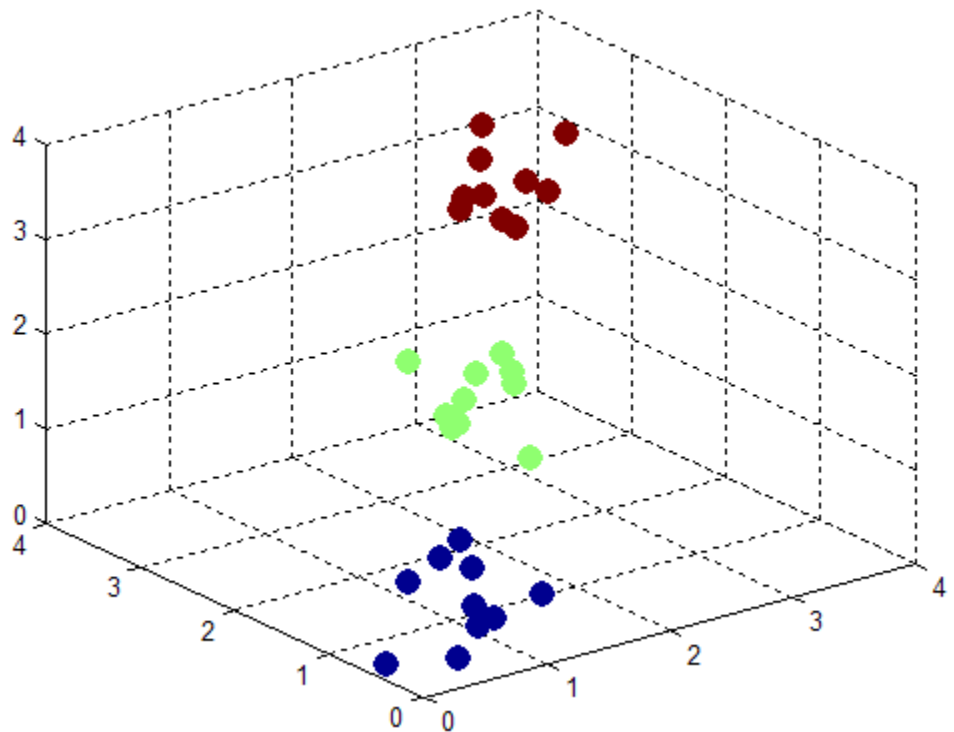
clusterdata

```
T = cluster(Z, 'maxclust', cutoff);
```

Examples

The example first creates a sample data set of random numbers. It then uses `clusterdata` to compute the distances between items in the data set and create a hierarchical cluster tree from the data set. Finally, the `clusterdata` function groups the items in the data set into three clusters. The example uses the `find` function to list all the items in cluster 2, and the `scatter3` function to plot the data with each cluster shown in a different color.

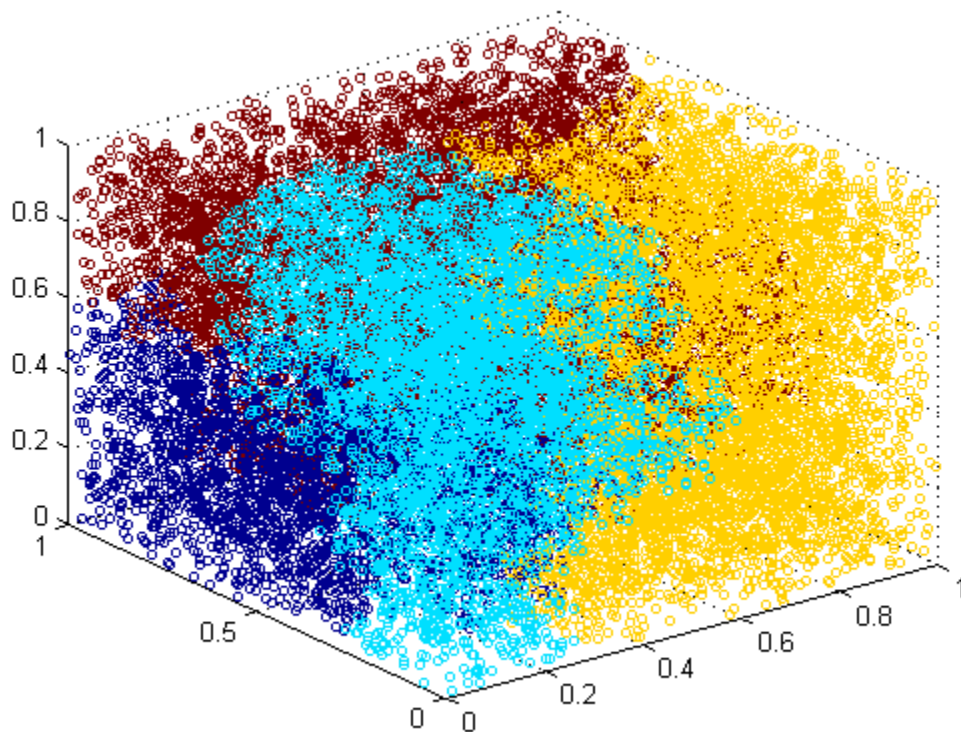
```
X = [gallery('uniformdata',[10 3],12);...  
gallery('uniformdata',[10 3],13)+1.2;...  
gallery('uniformdata',[10 3],14)+2.5];  
T = clusterdata(X,'maxclust',3);  
find(T==2)  
ans =  
    11  
    12  
    13  
    14  
    15  
    16  
    17  
    18  
    19  
    20  
scatter3(X(:,1),X(:,2),X(:,3),100,T,'filled')
```



Create a hierarchical cluster tree for a data with 20000 observations using Ward's linkage. If you set `savememory` to `'off'`, you can get an out-of-memory error if your machine doesn't have enough memory to hold the distance matrix.

```
X = rand(20000,3);  
c = clusterdata(X,'linkage','ward','savememory','on',...  
    'maxclust',4);  
scatter3(X(:,1),X(:,2),X(:,3),10,c)
```

clusterdata



See Also

[cluster](#) | [inconsistent](#) | [kmeans](#) | [linkage](#) | [pdist](#)

Purpose	Classical multidimensional scaling
Syntax	$Y = \text{cmdscale}(D)$ $[Y, e] = \text{cmdscale}(D)$
Description	<p>$Y = \text{cmdscale}(D)$ takes an n-by-n distance matrix D, and returns an n-by-p configuration matrix Y. Rows of Y are the coordinates of n points in p-dimensional space for some $p < n$. When D is a Euclidean distance matrix, the distances between those points are given by D. p is the dimension of the smallest space in which the n points whose inter-point distances are given by D can be embedded.</p> <p>$[Y, e] = \text{cmdscale}(D)$ also returns the eigenvalues of $Y*Y'$. When D is Euclidean, the first p elements of e are positive, the rest zero. If the first k elements of e are much larger than the remaining $(n-k)$, then you can use the first k columns of Y as k-dimensional points whose inter-point distances approximate D. This can provide a useful dimension reduction for visualization, e.g., for $k = 2$.</p> <p>D need not be a Euclidean distance matrix. If it is non-Euclidean or a more general dissimilarity matrix, then some elements of e are negative, and cmdscale chooses p as the number of positive eigenvalues. In this case, the reduction to p or fewer dimensions provides a reasonable approximation to D only if the negative elements of e are small in magnitude.</p> <p>You can specify D as either a full dissimilarity matrix, or in upper triangle vector form such as is output by <code>pdist</code>. A full dissimilarity matrix must be real and symmetric, and have zeros along the diagonal and positive elements everywhere else. A dissimilarity matrix in upper triangle form must have real, positive entries. You can also specify D as a full similarity matrix, with ones along the diagonal and all other elements less than one. <code>cmdscale</code> transforms a similarity matrix to a dissimilarity matrix in such a way that distances between the points returned in Y equal or approximate $\sqrt{1-D}$. To use a different transformation, you must transform the similarities prior to calling <code>cmdscale</code>.</p>

Examples

Generate some points in 4-D space, but close to 3-D space, then reduce them to distances only.

```
X = [normrnd(0,1,10,3) normrnd(0,.1,10,1)];  
D = pdist(X,'euclidean');
```

Find a configuration with those inter-point distances.

```
[Y,e] = cmdscale(D);  
  
% Four, but fourth one small  
dim = sum(e > eps^(3/4))  
  
% Poor reconstruction  
maxerr2 = max(abs(pdist(X)-pdist(Y(:,1:2))))  
  
% Good reconstruction  
maxerr3 = max(abs(pdist(X)-pdist(Y(:,1:3))))  
  
% Exact reconstruction  
maxerr4 = max(abs(pdist(X)-pdist(Y)))  
  
% D is now non-Euclidean  
D = pdist(X,'cityblock');  
[Y,e] = cmdscale(D);  
  
% One is large negative  
min(e)  
  
% Poor reconstruction  
maxerr = max(abs(pdist(X)-pdist(Y)))
```

References

[1] Seber, G. A. F. *Multivariate Observations*. Hoboken, NJ: John Wiley & Sons, Inc., 1984.

See Also

mdscale | pdist | procrustes

NaiveBayes.CNames property

Purpose

Class names

Description

The CNames property is an NClasses-by-1 cell array containing the group names, where NClasses number of groups in the grouping variable used to create the Naive Bayes classifier.

GeneralizedLinearModel.coefCI

Purpose Confidence intervals of coefficient estimates of generalized linear model

Syntax
`ci = coefCI mdl`
`ci = coefCI mdl, alpha`

Description
`ci = coefCI mdl` returns confidence intervals for the coefficients in `mdl`.
`ci = coefCI mdl, alpha` returns confidence intervals with confidence level $1 - \alpha$.

Input Arguments
mdl
Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

alpha
Scalar from 0 to 1, the probability that the confidence interval does not contain the true value.

Default: 0.05

Output Arguments
ci
k-by-2 matrix of confidence intervals. The *j*th row of `ci` is the confidence interval of coefficient *j* of `mdl`. The name of coefficient *j* of `mdl` is in `mdl.CoefficientNames`.

Definitions **Confidence Interval**

Assume that model assumptions hold (data comes from a generalized linear model represented by the formula `mdl.Formula` and the specified link function, and with observations that are independent conditional on the predictor values). Then row *j* of the confidence interval matrix `ci` gives a *confidence interval* [`ci(j,1)`, `ci(j,2)`] computed such that, with repeated experimentation, a proportion $1 - \alpha$ of the intervals will contain the true value of the coefficient.

Examples

Confidence Interval for Coefficients of a Generalized Linear Model

Find confidence intervals for the coefficients of a fitted generalized nonlinear model.

Generate artificial data for the model using Poisson random numbers with two underlying predictors $X(1)$ and $X(2)$.

```
rng('default') % for reproducibility
rndvars = randn(100,2);
X = [2+rndvars(:,1),rndvars(:,2)];
mu = exp(1 + X*[1;2]);
y = poissrnd(mu);
```

Create a generalized linear regression model of Poisson data.

```
mdl = GeneralizedLinearModel.fit(X,y,...
    'y ~ x1 + x2','distr','poisson')
```

```
mdl =
```

```
Generalized Linear regression model:
```

```
log(y) ~ 1 + x1 + x2
Distribution = Poisson
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	1.0405	0.022122	47.034	0
x1	0.9968	0.003362	296.49	0
x2	1.987	0.0063433	313.24	0

```
100 observations, 97 error degrees of freedom
```

```
Dispersion: 1
```

```
Chi^2-statistic vs. constant model: 2.95e+05, p-value = 0
```

Find 95% (default) confidence intervals on the coefficients of the model.

GeneralizedLinearModel.coefCI

```
ci = coefCI mdl
```

```
ci =
```

```
    0.9966    1.0844  
    0.9901    1.0035  
    1.9744    1.9996
```

Find 99% confidence intervals on the coefficients.

```
alpha = .01;  
ci = coefCI(mdl,alpha)
```

```
ci =
```

```
    0.9824    1.0986  
    0.9880    1.0056  
    1.9703    2.0036
```

See Also [GeneralizedLinearModel](#) |

Related Examples

- “Generalized Linear Model Workflow” on page 9-171

Purpose	Confidence intervals of coefficient estimates of linear model
Syntax	<pre>ci = coefCI mdl ci = coefCI mdl, alpha</pre>
Description	<p><code>ci = coefCI mdl</code> returns confidence intervals for the coefficients in <code>mdl</code>.</p> <p><code>ci = coefCI mdl, alpha</code> returns confidence intervals with confidence level $1 - \alpha$.</p>
Input Arguments	<p>mdl</p> <p>Linear model, as constructed by <code>LinearModel.fit</code> or <code>LinearModel.stepwise</code>.</p> <p>alpha</p> <p>Scalar from 0 to 1, the probability that the confidence interval does not contain the true value.</p> <p>Default: 0.05</p>
Output Arguments	<p>ci</p> <p>k-by-2 matrix of confidence intervals. The jth row of <code>ci</code> is the confidence interval of coefficient j of <code>mdl</code>. The name of coefficient j of <code>mdl</code> is in <code>mdl.CoefficientNames</code>.</p>
Definitions	<p>Confidence Interval</p> <p>Assume that model assumptions hold (data comes from a generalized linear model represented by the formula <code>mdl.Formula</code>, and with observations that are independent conditional on the predictor values). Then row j of the confidence interval matrix <code>ci</code> gives a <i>confidence interval</i> <code>[ci(j,1), ci(j,2)]</code> computed such that, with repeated experimentation, a proportion $1 - \alpha$ of the intervals will contain the true value of the coefficient.</p>

Examples

Default Confidence Intervals

Create a linear model for auto mileage based on the `carbig` data. Then obtain confidence intervals for the resulting model coefficients.

Load the data and create a model.

```
load carbig
Origin = nominal(Origin);
ds = dataset(Horsepower,Weight,MPG,Origin);
modelspec = 'MPG ~ 1 + Horsepower + Weight + Origin';
mdl = LinearModel.fit(ds,modelspec);
```

View the names of the coefficients.

```
mdl.CoeffNames
```

```
ans =
Columns 1 through 4
    '(Intercept)'    'Horsepower'    'Weight'    'Origin_France'

Columns 5 through 8
    'Origin_Germany'    'Origin_Italy'    'Origin_Japan'    'Origin_Sweden'

Column 9
    'Origin_USA'
```

Find confidence intervals for the coefficients of the model.

```
ci = coefCI(mdl)
```

```
ci =
    43.361    59.939
   -0.074778   -0.031499
  -0.0058669  -0.0037122
   -17.362    -0.34772
   -15.75     0.74338
   -17.209     0.0613
   -14.511     1.8738
```

```

-18.582    -1.5036
-17.311    -0.96419

```

Custom Confidence Intervals

Create a linear model for auto mileage based on the `carbig` data. Then obtain confidence intervals for the resulting model coefficients at the 99% level.

Load the data and create a model.

```

load carbig
Origin = nominal(Origin);
ds = dataset(Horsepower,Weight,MPG,Origin);
modelspec = 'MPG ~ 1 + Horsepower + Weight + Origin';
mdl = LinearModel.fit(ds,modelspec);

```

Find 99% confidence intervals for the coefficients.

```

ci = coefCI(mdl,.01)

ci =
    40.737    62.564
   -0.081629   -0.024647
   -0.006208   -0.0033711
   -20.056     2.3459
   -18.361     3.3546
   -19.943     2.7955
   -17.104     4.4676
   -21.286     1.2002
   -19.899     1.6238

```

The confidence intervals are wider than the default 5% confidence intervals of “Default Confidence Intervals” on page 20-284.

Alternatives

You can create the intervals from the model coefficients in `mdl.Coefficients.Estimate` and an appropriate multiplier of the standard errors `sqrt(diag(mdl.CoefficientCovariance))`. The multiplier is `tinv(1-alpha/2,dof)`, where `level` is the confidence

LinearModel.coefCI

level, and dof is the degrees of freedom (number of data points minus the number of coefficients).

See Also `LinearModel`

How To • “Linear Regression” on page 9-7

Purpose	Confidence intervals of coefficient estimates of nonlinear regression model
Syntax	<code>ci = coefCI mdl</code> <code>ci = coefCI mdl, alpha</code>
Description	<code>ci = coefCI mdl</code> returns confidence intervals for the coefficients in <code>mdl</code> . <code>ci = coefCI mdl, alpha</code> returns confidence intervals with confidence level $1 - \alpha$.
Input Arguments	mdl Nonlinear regression model, constructed by <code>NonLinearModel.fit</code> . alpha Scalar from 0 to 1, the probability that the confidence interval does not contain the true value. Default: 0.05
Output Arguments	ci k-by-2 matrix of confidence intervals. The <i>j</i> th row of <code>ci</code> is the confidence interval of coefficient <i>j</i> of <code>mdl</code> . The name of coefficient <i>j</i> of <code>mdl</code> is in <code>mdl.CoeffNames</code> .
Definitions	Confidence Interval Assume that model assumptions hold (the data comes from a model represented by the formula <code>mdl.Formula</code> , with independent normally distributed errors). Then row <i>j</i> of the confidence interval matrix <code>ci</code> gives a <i>confidence interval</i> <code>[ci(j,1), ci(j,2)]</code> that contains coefficient <i>j</i> with probability $1 - \alpha$.

Examples

Default Confidence Intervals

Create a nonlinear model for auto mileage based on the `carbig` data. Then obtain confidence intervals for the resulting model coefficients.

Load the data and create a nonlinear model.

```
load carbig
ds = dataset(Horsepower,Weight,MPG);
modelfun = @(b,x)b(1) + b(2)*x(:,1) + ...
    b(3)*x(:,2) + b(4)*x(:,1).*x(:,2);
beta0 = [1 1 1 1];
mdl = NonLinearModel.fit(ds,modelfun,beta0)
```

```
mdl =
```

```
Nonlinear regression model:
```

```
MPG ~ b1 + b2*Horsepower + b3*Weight + b4*Horsepower*Weight
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
b1	63.558	2.3429	27.127	1.2343e-91
b2	-0.25084	0.027279	-9.1952	2.3226e-18
b3	-0.010772	0.00077381	-13.921	5.1372e-36
b4	5.3554e-05	6.6491e-06	8.0542	9.9336e-15

```
Number of observations: 392, Error degrees of freedom: 388
```

```
Root Mean Squared Error: 3.93
```

```
R-Squared: 0.748, Adjusted R-Squared 0.746
```

```
F-statistic vs. constant model: 385, p-value = 7.26e-116
```

All the coefficients have extremely small p -values. This means a confidence interval around the coefficients will not contain the point 0, unless the confidence level is very high.

Find 95% confidence intervals for the coefficients of the model.

```
ci = coefCI(mdl)
```

```
ci =  
  
    58.9515    68.1644  
   -0.3045   -0.1972  
   -0.0123   -0.0093  
    0.0000    0.0001
```

The confidence interval for `b4` seems to contain 0. Examine it in more detail.

```
ci(4,:)

ans =  
    1.0e-04 *  
    0.4048    0.6663
```

As expected, the confidence interval does not contain the point 0.

Alternatives

You can create the intervals from the model coefficients in `mdl.Coefficients.Estimate` and an appropriate multiplier of the standard errors `sqrt(diag(mdl.CoefficientCovariance))`. The multiplier is `tinu(1-alpha/2,dof)`, where `level` is the confidence level, and `dof` is the degrees of freedom (number of data points minus the number of coefficients).

See Also `NonLinearModel` |

Related Examples

- “Nonlinear Regression Workflow” on page 9-210

Concepts

- “Nonlinear Regression” on page 9-196

GeneralizedLinearModel.coefTest

Purpose Linear hypothesis test on generalized linear regression model coefficients

Syntax

```
p = coefTest mdl
p = coefTest mdl,H
p = coefTest mdl,H,C
[p,F] = coefTest mdl,...
[p,F,r] = coefTest mdl,...
```

Description

`p = coefTest(mdl)` computes the p -value for an F test that all coefficient estimates in `mdl` are zero, except for the intercept term.

`p = coefTest(mdl,H)` performs an F test that $H*B = 0$, where B represents the coefficient vector.

`p = coefTest(mdl,H,C)` performs an F test that $H*B = C$.

`[p,F] = coefTest(mdl,...)` returns the F test statistic.

`[p,F,r] = coefTest(mdl,...)` returns the numerator degrees of freedom for the test.

Input Arguments

mdl

Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

H

Numeric matrix having one column for each coefficient in the model. When H is an input, the output p is the p -value for an F test that $H*B = 0$, where B represents the coefficient vector.

C

Numeric vector with the same number of rows as H . When C is an input, the output p is the p -value for an F test that $H*B = C$, where B represents the coefficient vector.

Output Arguments

p

p -value of the F test (see “Definitions” on page 20-291).

F

Value of the test statistic for the F test (see “Definitions” on page 20-291).

r

Numerator degrees of freedom for the F test (see “Definitions” on page 20-291). The F statistic has r degrees of freedom in the numerator and `mdl.DFE` degrees of freedom in the denominator.

Definitions

Test Statistics

The p -value, F statistic, and numerator degrees of freedom are valid under these assumptions:

- The data comes from a model represented by the formula `mdl.Formula`.
- The observations are independent conditional on the predictor values.

Suppose these assumptions hold. Let β represent the (unknown) coefficient vector of the linear regression. Suppose H is a full-rank matrix of size r -by- s , where s is the number of terms in β . Let v be a vector the same size as β . The following is a test statistic for the hypothesis that $H\beta = v$:

$$F = (H\hat{\beta} - v)'(HCH')^{-1}(H\hat{\beta} - v).$$

Here $\hat{\beta}$ is the estimate of the coefficient vector β in `mdl.Coeffs`, and C is the estimated covariance of the coefficient estimates in `mdl.CoeffCov`. When the hypothesis is true, the test statistic F has an “F Distribution” on page B-38 with r and u degrees of freedom.

GeneralizedLinearModel.coefTest

Examples

Test Generalized Linear Model Coefficients

Test a generalized linear model to see if its coefficients differ from zero.

Create a generalized linear regression model of Poisson data.

```
X = 2 + randn(100,1);  
mu = exp(1 + X/2);  
y = poissrnd(mu);  
mdl = GeneralizedLinearModel.fit(X,y,...  
    'y ~ x1','distr','poisson');
```

Test whether the fitted model has coefficients that differ significantly from zero.

```
p = coefTest(mdl)
```

```
p =
```

```
1.2461e-30
```

There is no doubt that the coefficient of x_1 is nonzero.

Alternatives

The values of commonly used test statistics are available in the `mdl.Coefficients` dataset array.

See Also

[GeneralizedLinearModel](#) | [linhyptest](#)

Related Examples

- “Generalized Linear Model Workflow” on page 9-171

Concepts

- “Generalized Linear Models” on page 9-141

Purpose

Linear hypothesis test on linear regression model coefficients

Syntax

```
p = coefTest mdl
p = coefTest mdl,H
p = coefTest mdl,H,C
[p,F] = coefTest mdl,...
[p,F,r] = coefTest mdl,...
```

Description

`p = coefTest(mdl)` computes the p -value for an F test that all coefficient estimates in `mdl` are zero, except for the intercept term.

`p = coefTest(mdl,H)` performs an F test that $H*B = 0$, where B represents the coefficient vector.

`p = coefTest(mdl,H,C)` performs an F test that $H*B = C$.

`[p,F] = coefTest(mdl,...)` returns the F test statistic.

`[p,F,r] = coefTest(mdl,...)` returns the numerator degrees of freedom for the test.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

H

Numeric matrix having one column for each coefficient in the model. When H is an input, the output p is the p -value for an F test that $H*B = 0$, where B represents the coefficient vector.

C

Numeric vector with the same number of rows as H . When C is an input, the output p is the p -value for an F test that $H*B = C$, where B represents the coefficient vector.

Output Arguments

p

p -value of the F test (see “Definitions” on page 20-294).

F

Value of the test statistic for the F test (see “Definitions” on page 20-294).

r

Numerator degrees of freedom for the F test (see “Definitions” on page 20-294). The F statistic has r degrees of freedom in the numerator and `mdl.DFE` degrees of freedom in the denominator.

Definitions

Test Statistics

The p -value, F statistic, and numerator degrees of freedom are valid under these assumptions:

- The data comes from a model represented by the formula `mdl.Formula`.
- The observations are independent conditional on the predictor values.

Suppose these assumptions hold. Let β represent the (unknown) coefficient vector of the linear regression. Suppose H is a full-rank matrix of size r -by- s , where s is the number of terms in β . Let v be a vector the same size as β . The following is a test statistic for the hypothesis that $H\beta = v$:

$$F = (H\hat{\beta} - v)'(HCH')^{-1}(H\hat{\beta} - v).$$

Here $\hat{\beta}$ is the estimate of the coefficient vector β in `mdl.Coeffs`, and C is the estimated covariance of the coefficient estimates in `mdl.CoeffCov`. When the hypothesis is true, the test statistic F has an “F Distribution” on page B-38 with r and u degrees of freedom.

Examples

Test Linear Regression Model

Make a linear model of mileage as a function of the weight, weight squared, and model year from the `carsmall` data set. Test the coefficients to see if all should be zero.

Load the data and make a dataset array, where the model year is an ordinal variable.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight + Weight^2');
```

Test the model for significant differences from a constant model.

```
p = coefTest(mdl)
```

```
p =
```

```
5.5208e-41
```

There is no doubt that the model contains more than the intercept term.

Test a Particular Coefficient

Test the Weight^2 coefficient in a linear model of mileage as a function of the weight, weight squared, and model year.

Load the data and make a dataset array, where the model year is an ordinal variable.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight + Weight^2');
```

Test the significance of the Weight^2 coefficient. To do so, find the coefficient corresponding to Weight^2 .

```
mdl.CoefficientNames
```

```
ans =
```

```
'(Intercept)' 'Weight' 'Year_76' 'Year_82' 'Weight^2'
```

LinearModel.coefTest

Weight² is the fifth (final) coefficient.

Test the significance of the Weight² coefficient.

```
p = coefTest mdl,[0 0 0 0 1])
```

```
p =
```

```
0.0022
```

Alternatives

The values of commonly used test statistics are available in the `mdl.Coefficients` dataset array.

`anova` provides a test for each model term.

See Also

`anova` | `LinearModel` | `linhyptest`

How To

- “Linear Regression” on page 9-7

Purpose Linear hypothesis test on nonlinear regression model coefficients

Syntax

```
p = coefTest mdl
p = coefTest mdl,H
p = coefTest mdl,H,C
[p,F] = coefTest mdl,...
[p,F,r] = coefTest mdl,...
```

Description

`p = coefTest(mdl)` computes the p -value for an F test that all coefficient estimates in `mdl` are zero.

`p = coefTest(mdl,H)` performs an F test that $H*B = 0$, where B represents the coefficient vector.

`p = coefTest(mdl,H,C)` performs an F test that $H*B = C$.

`[p,F] = coefTest(mdl,...)` returns the F test statistic.

`[p,F,r] = coefTest(mdl,...)` returns the numerator degrees of freedom for the test.

Input Arguments

mdl

Nonlinear regression model, constructed by `NonLinearModel.fit`.

H

Numeric matrix having one column for each coefficient in the model. When H is an input, the output p is the p -value for an F test that $H*B = 0$, where B represents the coefficient vector.

C

Numeric vector with the same number of rows as H . When C is an input, the output p is the p -value for an F test that $H*B = C$, where B represents the coefficient vector.

Output Arguments

p

p -value of the F test (see “Definitions” on page 20-298).

F

Value of the test statistic for the F test (see “Definitions” on page 20-298).

r

Numerator degrees of freedom for the F test (see “Definitions” on page 20-298). The F statistic has r degrees of freedom in the numerator and $mdl.DFE$ degrees of freedom in the denominator.

Definitions

Test Statistics

The p -value, F statistic, and numerator degrees of freedom are valid under these assumptions:

- The data comes from a normal distribution.
- The entries are independent.

Suppose these assumptions hold. Let β represent the unknown coefficient vector of the linear regression. Suppose H is a full-rank matrix of size r -by- s , where s is the number of terms in β . Let v be a vector the same size as β . The following is a test statistic for the hypothesis that $H\beta = v$:

$$F = (H\hat{\beta} - v)'(HCH')^{-1}(H\hat{\beta} - v).$$

Here $\hat{\beta}$ is the estimate of the coefficient vector β in `mdl.Coeffs`, and C is the estimated covariance of the coefficient estimates in `mdl.CoeffCov`. When the hypothesis is true, the test statistic F has an “F Distribution” on page B-38 with r and u degrees of freedom.

Examples

Test Nonlinear Regression Model Coefficients

Make a nonlinear model of mileage as a function of the weight from the `carsmall` data set. Test the coefficients to see if all should be zero.

Create an exponential model of car mileage as a function of weight from the `carsmall` data. Scale the weight by a factor of 1000 so all the variables are roughly equal in size.

```
load carsmall
X = Weight;
y = MPG;
modelfun = 'y ~ b1 + b2*exp(-b3*x/1000)';
beta0 = [1 1 1];
mdl = NonLinearModel.fit(X,y,modelfun,beta0);
```

Test the model for significant differences from a constant model.

```
p = coefTest(mdl)
```

```
p =
```

```
1.3708e-36
```

There is no doubt that the model contains nonzero terms.

Alternatives The values of commonly used test statistics are available in the `mdl.Coefficients` dataset array.

See Also `NonLinearModel` |

Concepts

- “Nonlinear Regression” on page 9-196

CompactTreeBagger.combine

Purpose Combine two ensembles

Syntax `B1 = combine(B1,B2)`

Description `B1 = combine(B1,B2)` appends decision trees from ensemble B2 to those stored in B1 and returns ensemble B1. This method requires that the class and variable names be identical in both ensembles.

See Also `TreeBagger.append`

Purpose Enumeration of combinations

Syntax `C = combnk(v,k)`

Description `C = combnk(v,k)` returns all combinations of the n elements in v taken k at a time.

`C = combnk(v,k)` produces a matrix C with k columns and $n!/k!(n-k)!$ rows, where each row contains k of the elements in the vector v .

It is not practical to use this function if v has more than about 15 elements.

Examples Combinations of characters from a string.

```
C = combnk('tendrill',4);
last5 = C(31:35,:);
last5 =
tedr
tenl
teni
tenr
tend
```

Combinations of elements from a numeric vector.

```
c = combnk(1:4,2)
c =
 3  4
 2  4
 2  3
 1  4
 1  3
 1  2
```

See Also `perms`

ClassificationDiscriminant.compact

Purpose	Compact discriminant analysis classifier
Syntax	<code>cobj = compact(obj)</code>
Description	<code>cobj = compact(obj)</code> creates a compact version of <code>obj</code> .
Input Arguments	obj Discriminant analysis classifier created using <code>ClassificationDiscriminant.fit</code> .
Output Arguments	cobj Compact classifier. <code>cobj</code> has class <code>CompactClassificationDiscriminant</code> . You can predict classifications using <code>cobj</code> exactly as you can using <code>obj</code> . However, since <code>cobj</code> does not contain training data, you cannot perform some actions, such as cross validation.
Examples	Compare the size of the discriminant analysis classifier for Fisher's iris data to the compact version of the classifier: <pre>load fisheriris fullobj = ClassificationDiscriminant.fit(meas,species); cobj = compact(fullobj); b = whos('fullobj'); % b.bytes = size of fullobj c = whos('cobj'); % c.bytes = size of cobj [b.bytes c.bytes] % shows cobj uses 60% of the memory</pre> <pre>ans = 18578 11498</pre>
See Also	<code>ClassificationDiscriminant</code>
How To	• “Discriminant Analysis” on page 12-3

Purpose	Compact classification ensemble
Syntax	<code>cens = compact(ens)</code>
Description	<code>cens = compact(ens)</code> creates a compact version of <code>ens</code> . You can predict classifications using <code>cens</code> exactly as you can using <code>ens</code> . However, since <code>cens</code> does not contain training data, you cannot perform some actions, such as cross validation.
Input Arguments	ens A classification ensemble created with <code>fitensemble</code> .
Output Arguments	cens A compact classification ensemble. <code>cens</code> has class <code>CompactClassificationEnsemble</code> .
Examples	Compare the size of a classification ensemble for Fisher's iris data to the compact version of the ensemble: <pre>load fisheriris ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree'); cens = compact(ens); b = whos('ens'); % b.bytes = size of ens c = whos('cens'); % c.bytes = size of ens [b.bytes c.bytes] % shows cens uses less memory</pre> <pre>ans = 571727 532476</pre>
See Also	<code>ClassificationTree</code> <code>fitensemble</code>
How To	• “Ensemble Methods” on page 13-54

ClassificationTree.compact

Purpose	Compact tree
Syntax	<code>ctree = compact(tree)</code>
Description	<code>ctree = compact(tree)</code> creates a compact version of <code>tree</code> .
Input Arguments	tree A classification tree created using <code>ClassificationTree.fit</code> .
Output Arguments	ctree A compact decision tree. <code>ctree</code> has class <code>CompactClassificationTree</code> . You can predict classifications using <code>ctree</code> exactly as you can using <code>tree</code> . However, since <code>ctree</code> does not contain training data, you cannot perform some actions, such as cross validation.
Examples	Compare the size of the classification tree for Fisher's iris data to the compact version of the tree: <pre>load fisheriris fulltree = ClassificationTree.fit(meas,species); ctree = compact(fulltree); b = whos('fulltree'); % b.bytes = size of fulltree c = whos('ctree'); % c.bytes = size of ctree [b.bytes c.bytes] % shows ctree uses half the memory</pre> <pre>ans = 13913 6818</pre>
See Also	<code>CompactClassificationTree</code> <code>ClassificationTree</code> <code>predict</code>

Purpose	Create compact regression ensemble
Syntax	<code>cens = compact(ens)</code>
Description	<code>cens = compact(ens)</code> creates a compact version of <code>ens</code> . You can predict regressions using <code>cens</code> exactly as you can using <code>ens</code> . However, since <code>cens</code> does not contain training data, you cannot perform some actions, such as cross validation.
Input Arguments	ens A regression ensemble created with <code>fitensemble</code> .
Output Arguments	cens A compact regression ensemble. <code>cens</code> is of class <code>CompactRegressionEnsemble</code> .
Examples	<p>Compare the size of a regression ensemble for the <code>carsmall</code> data to the compact version of the ensemble:</p> <pre>load carsmall X = [Acceleration Cylinders Displacement Horsepower Weight]; ens = fitensemble(X,MPG,'LSBoost',100,'Tree'); cens = compact(ens); b = whos('ens'); % b.bytes = size of ens c = whos('cens'); % c.bytes = size of cens [b.bytes c.bytes] % shows ctree uses less memory</pre> <p>ans =</p> <pre> 311789 287368</pre>
See Also	<code>RegressionEnsemble</code> <code>CompactRegressionEnsemble</code>

RegressionTree.compact

Purpose	Compact regression tree
Syntax	<code>ctree = compact(tree)</code>
Description	<code>ctree = compact(tree)</code> creates a compact version of <code>tree</code> .
Input Arguments	tree A regression tree created using <code>RegressionTree.fit</code> .
Output Arguments	ctree A compact regression tree. <code>ctree</code> has class <code>CompactRegressionTree</code> . You can predict regressions using <code>ctree</code> exactly as you can using <code>tree</code> . However, since <code>ctree</code> does not contain training data, you cannot perform some actions, such as cross validation.
Examples	Compare the size of a regression tree for the <code>carsmall</code> data to the compact version of the tree: <pre>load carsmall X = [Acceleration Cylinders Displacement Horsepower Weight]; fulltree = RegressionTree.fit(X,MPG); ctree = compact(fulltree); b = whos('fulltree'); % b.bytes = size of fulltree c = whos('ctree'); % c.bytes = size of ctree [b.bytes c.bytes] % shows ctree uses 2/3 the memory ans = 15715 10258</pre>
See Also	<code>CompactRegressionTree</code> <code>RegressionTree</code> <code>predict</code>

Purpose

Compact ensemble of decision trees

Description

Return an object of class `CompactTreeBagger` holding the structure of the trained ensemble. The class is more compact than the full `TreeBagger` class because it does not contain information for growing more trees for the ensemble. In particular, it does not contain `X` and `Y` used for training.

See Also

`CompactTreeBagger`

CompactClassificationDiscriminant

Purpose Compact discriminant analysis class

Description A `CompactClassificationDiscriminant` object is a compact version of a discriminant analysis classifier. The compact version does not include the data for training the classifier. Therefore, you cannot perform some tasks with a compact classifier, such as cross validation. Use a compact classifier for making predictions (classifications) of new data.

Construction `cobj = compact(obj)` constructs a compact classifier from a full classifier.

`cobj = ClassificationDiscriminant.make(Mu,Sigma)` constructs a compact discriminant analysis classifier from the class means `Mu` and covariance matrix `Sigma`. For syntax details, see `ClassificationDiscriminant.make`.

Input Arguments

obj

Discriminant analysis classifier, created with `ClassificationDiscriminant.fit`.

Properties

BetweenSigma

p-by-p matrix, the between-class covariance, where p is the number of predictors.

CategoricalPredictors

List of categorical predictors, always empty (`[]`) for discriminant analysis.

ClassNames

List of the elements in the training data `Y` with duplicates removed. `ClassNames` can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. `ClassNames` has the same data type as the data in the argument `Y`.

Coeffs

k-by-k structure of coefficient matrices, where k is the number of classes. `Coeffs(i, j)` contains coefficients of the linear or quadratic boundaries between classes i and j. Fields in `Coeffs(i, j)`:

- `DiscrimType`
- `Class1` — `ClassNames(i)`
- `Class2` — `ClassNames(j)`
- `Const` — A scalar
- `Linear` — A vector with p components, where p is the number of columns in X
- `Quadratic` — p-by-p matrix, exists for quadratic `DiscrimType`

The equation of the boundary between class i and class j is

$$\text{Const} + \text{Linear} * x + x' * \text{Quadratic} * x = 0,$$

where x is a column vector of length p.

If `ClassificationDiscriminant.fit` had the `FillCoeffs` name-value pair set to 'off' when constructing the classifier, `Coeffs` is empty (`[]`).

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class j if its true class is i. `Cost` is K-by-K, where K is the number of classes.

Change a `Cost` matrix using dot addressing:

```
obj.Cost = costMatrix
```

Delta

CompactClassificationDiscriminant

Value of the Delta threshold for a linear discriminant model, a nonnegative scalar. If a coefficient of `obj` has magnitude smaller than `Delta`, `obj` sets this coefficient to 0, and so you can eliminate the corresponding predictor from the model. Set `Delta` to a higher value to eliminate more predictors.

`Delta` must be 0 for quadratic discriminant models.

Change `Delta` by dot addressing:

```
obj.Delta = newDelta
```

DeltaPredictor

Row vector of length equal to the number of predictors in `obj`. If `DeltaPredictor(i) < Delta` then coefficient `i` of the model is 0.

If `obj` is a quadratic discriminant model, all elements of `DeltaPredictor` are 0.

DiscrimType

String specifying the discriminant type. One of:

- 'linear'
- 'quadratic'
- 'diagLinear'
- 'diagQuadratic'
- 'pseudoLinear'
- 'pseudoQuadratic'

Change `DiscrimType` using dot addressing:

```
obj.DiscrimType = newDiscrimType
```

You can change between linear types, or between quadratic types, but cannot change between linear and quadratic types.

Gamma

Value of the Gamma regularization parameter, a scalar from 0 to 1. Change Gamma using dot addressing:

```
obj.Gamma = newGamma
```

- If you set 1 for linear discriminant, the discriminant sets its type to 'diagLinear'.
- If you set a value between MinGamma and 1 for linear discriminant, the discriminant sets its type to 'linear'.
- You cannot set values below the value of the MinGamma property.
- For quadratic discriminant, you can set either 0 (for DiscrimType 'quadratic') or 1 (for DiscrimType 'diagQuadratic').

LogDetSigma

Logarithm of the determinant of the within-class covariance matrix. The type of LogDetSigma depends on the discriminant type:

- Scalar for linear discriminant analysis
- Vector of length K for quadratic discriminant analysis, where K is the number of classes

MinGamma

Nonnegative scalar, the minimal value of the Gamma parameter so that the correlation matrix is invertible. If the correlation matrix is not singular, MinGamma is 0.

Mu

Matrix of class means of size K-by-p, where K is the number of classes, and p is the number of predictors. Each row of Mu represents the mean of the multivariate normal distribution of the corresponding class. The class indices are in the ClassNames attribute.

CompactClassificationDiscriminant

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in the training data X.

Prior

Prior probabilities for each class. `Prior` is a numeric vector whose entries relate to the corresponding `ClassNames` property.

Add or change a `Prior` vector using dot addressing:

```
obj.Prior = priorVector
```

ResponseName

String describing the response variable Y.

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$. For a list of built-in transformation functions and the syntax of custom transformation functions, see `ClassificationDiscriminant.fit`.

Add or change a `ScoreTransform` function by dot addressing:

```
obj.ScoreTransform = 'function'
```

or

```
obj.ScoreTransform = @function
```

Sigma

Within-class covariance matrix or matrices. The dimensions depend on `DiscrimType`:

- 'linear' (default) — Matrix of size p-by-p, where p is the number of predictors

- 'quadratic' — Array of size p -by- p -by- K , where K is the number of classes
- 'diagLinear' — Row vector of length p
- 'diagQuadratic' — Array of size 1 -by- p -by- K
- 'pseudoLinear' — Matrix of size p -by- p
- 'pseudoQuadratic' — Array of size p -by- p -by- K

Methods

edge	Classification edge
logP	Log of the unconditional probability density
loss	Classification error
mahal	Mahalanobis distance to class means
margin	Classification margins
nLinearCoeffs	Number of nonzero linear coefficients
predict	Predict classification

Definitions

Discriminant Classification

The model for discriminant analysis is:

- Each class (Y) generates data (X) using a multivariate normal distribution. That is, the model assumes X has a Gaussian mixture distribution (`gmdistribution`).
 - For linear discriminant analysis, the model has the same covariance matrix for each class, only the means vary.
 - For quadratic discriminant analysis, both means and covariances of each class vary.

Compact Classification Discriminant

predict classifies so as to minimize the expected classification cost:

$$\hat{y} = \arg \min_{y=1, \dots, K} \sum_{k=1}^K \hat{P}(k | x) C(y | k),$$

where

- \hat{y} is the predicted classification.
- K is the number of classes.
- $\hat{P}(k | x)$ is the posterior probability of class k for observation x .
- $C(y | k)$ is the cost of classifying an observation as y when its true class is k .

For details, see “How the predict Method Classifies” on page 12-6.

Regularization

Regularization is the process of finding a small set of predictors that yield an effective predictive model. For linear discriminant analysis, there are two parameters, γ and δ , that control regularization as follows. `cvshrink` helps you select appropriate values of the parameters.

Let Σ represent the covariance matrix of the data X , and let \hat{X} be the centered data (the data X minus the mean by class). Define

$$D = \text{diag}(\hat{X}^T * \hat{X}).$$

The regularized covariance matrix $\tilde{\Sigma}$ is

$$\tilde{\Sigma} = (1 - \gamma)\Sigma + \gamma D.$$

Whenever $\gamma \geq \text{MinGamma}$, $\tilde{\Sigma}$ is nonsingular.

Let μ_k be the mean vector for those elements of X in class k , and let μ_0 be the global mean vector (the mean of the rows of X). Let C be

the correlation matrix of the data X , and let \tilde{C} be the regularized correlation matrix:

$$\tilde{C} = (1 - \gamma)C + \gamma I,$$

where I is the identity matrix.

The linear term in the regularized discriminant analysis classifier for a data point x is

$$(x - \mu_0)^T \tilde{\Sigma}^{-1} (\mu_k - \mu_0) = \left[(x - \mu_0)^T D^{-1/2} \right] \left[\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right].$$

The parameter δ enters into this equation as a threshold on the final term in square brackets. Each component of the vector

$\left[\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right]$ is set to zero if it is smaller in magnitude than the threshold δ . Therefore, for class k , if component j is thresholded to zero, component j of x does not enter into the evaluation of the posterior probability.

The `DeltaPredictor` property is a vector related to this threshold. When $\delta \geq \text{DeltaPredictor}(i)$, all classes k have

$$\left| \tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right| \leq \delta.$$

Therefore, when $\delta \geq \text{DeltaPredictor}(i)$, the regularized classifier does not use predictor i .

Copy Semantics

Value. To learn how value classes affect copy operations, see [Copying Objects in the MATLAB Programming Fundamentals documentation](#).

Examples

Construct a compact discriminant analysis classifier for the Fisher iris data, and compare its size to that of the full classifier:

```
load fisheriris
fullobj = ClassificationDiscriminant.fit(meas,species);
```

CompactClassificationDiscriminant

```
cobj = compact(fullobj);
b = whos('fullobj'); % b.bytes = size of fullobj
c = whos('cobj'); % c.bytes = size of cobj
[b.bytes c.bytes] % shows cobj uses 60% of the memory

ans =
      18578      11498
```

Construct a compact discriminant analysis classifier from the means and covariances of the Fisher iris data:

```
load fisheriris
mu(1,:) = mean(meas(1:50,:));
mu(2,:) = mean(meas(51:100,:));
mu(3,:) = mean(meas(101:150,:));

mm1 = repmat(mu(1,:),50,1);
mm2 = repmat(mu(2,:),50,1);
mm3 = repmat(mu(3,:),50,1);
cc = meas;
cc(1:50,:) = cc(1:50,:) - mm1;
cc(51:100,:) = cc(51:100,:) - mm2;
cc(101:150,:) = cc(101:150,:) - mm3;
sigstar = cc' * cc / 147;
cpct = ClassificationDiscriminant.make(mu,sigstar,...
    'ClassNames',{'setosa','versicolor','virginica'});
```

See Also

ClassificationDiscriminant | compact |
ClassificationDiscriminant.make | predict

How To

- “Discriminant Analysis” on page 12-3

Purpose	Compact classification ensemble class
Description	Compact version of a classification ensemble (of class <code>ClassificationEnsemble</code>). The compact version does not include the data for training the classification ensemble. Therefore, you cannot perform some tasks with a compact classification ensemble, such as cross validation. Use a compact classification ensemble for making predictions (classifications) of new data.
Construction	<code>ens = compact(ens)</code> constructs a compact decision ensemble from a full decision ensemble.
	Input Arguments
	ens A classification ensemble created by <code>fitensemble</code> .
Properties	CategoricalPredictors List of categorical predictors. <code>CategoricalPredictors</code> is a numeric vector with indices from 1 to p , where p is the number of columns of X .
	ClassNames List of the elements in Y with duplicates removed. <code>ClassNames</code> can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. <code>ClassNames</code> has the same data type as the data in the argument Y .
	CombineWeights String describing how <code>ens</code> combines weak learner weights, either 'WeightedSum' or 'WeightedAverage'.
	Cost Square matrix where <code>Cost(i, j)</code> is the cost of classifying a point into class j if its true class is i .
	NTrained

CompactClassificationEnsemble

Number of trained weak learners in `cens`, a scalar.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

Prior

Prior probabilities for each class. `Prior` is a numeric vector whose entries relate to the corresponding `ClassNames` property.

ResponseName

String with the name of the response variable `Y`.

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means `@(x)x`. For a list of built-in transformation functions and the syntax of custom transformation functions, see `ClassificationTree.fit`.

Add or change a `ScoreTransform` function by dot addressing:

```
cens.ScoreTransform = 'function'
```

or

```
cens.ScoreTransform = @function
```

Trained

Trained learners, a cell array of compact classification models.

TrainedWeights

Numeric vector of trained weights for the weak learners in `ens`. `TrainedWeights` has `T` elements, where `T` is the number of weak learners in `learners`.

UsePredForLearner

Logical matrix of size P-by-NTrained, where P is the number of predictors (columns) in the training data X. UsePredForLearner(i, j) is true when learner j uses predictor i, and is false otherwise. For each learner, the predictors have the same order as the columns in the training data X.

If the ensemble is not of type Subspace, all entries in UsePredForLearner are true.

Methods

edge	Classification edge
loss	Classification error
margin	Classification margins
predict	Predict classification
predictorImportance	Estimates of predictor importance
removeLearners	Remove members of compact classification ensemble

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Create a compact classification ensemble for the ionosphere data:

```
load ionosphere
ens = fitensemble(X,Y,'AdaBoostM1',100,'Tree');
cens = compact(ens)

cens =
classreg.learning.classif.CompactClassificationEnsemble:
    PredictorNames: {1x34 cell}
    CategoricalPredictors: []
    ResponseName: 'Y'
    ClassNames: {'b' 'g'}
    ScoreTransform: 'none'
```

CompactClassificationEnsemble

NTrained: 100

See Also

`fitensemble` | `ClassificationEnsemble` | `predict` | `compact`

Purpose	Compact classification tree
Description	Compact version of a classification tree (of class <code>ClassificationTree</code>). The compact version does not include the data for training the classification tree. Therefore, you cannot perform some tasks with a compact classification tree, such as cross validation. Use a compact classification tree for making predictions (classifications) of new data.
Construction	<code>ctree = compact(tree)</code> constructs a compact decision tree from a full decision tree.
	Input Arguments
	tree A decision tree constructed by <code>ClassificationTree.fit</code> .
Properties	CategoricalPredictors List of categorical predictors. <code>CategoricalPredictors</code> is a numeric vector with indices from 1 to p , where p is the number of columns of X .
	CatSplit An n -by-2 cell array, where n is the number of categorical splits in <code>tree</code> . Each row in <code>CatSplit</code> gives left and right values for a categorical split. For each branch node with categorical split j based on a categorical predictor variable z , the left child is chosen if z is in <code>CatSplit(j,1)</code> and the right child is chosen if z is in <code>CatSplit(j,2)</code> . The splits are in the same order as nodes of the tree. Find the nodes for these splits by selecting 'categorical' cuts from top to bottom in the <code>CutType</code> property.
	Children An n -by-2 array containing the numbers of the child nodes for each node in <code>tree</code> , where n is the number of nodes. Leaf nodes have child node 0.
	ClassCount

CompactClassificationTree

An n -by- k array of class counts for the nodes in `tree`, where n is the number of nodes and k is the number of classes. For any node number i , the class counts `ClassCount(i, :)` are counts of observations (from the data used in fitting the tree) from each class satisfying the conditions for node i .

ClassNames

List of the elements in `Y` with duplicates removed. `ClassNames` can be a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. `ClassNames` has the same data type as the data in the argument `Y`.

ClassProb

An n -by- k array of class probabilities for the nodes in `tree`, where n is the number of nodes and k is the number of classes. For any node number i , the class probabilities `ClassProb(i, :)` are the estimated probabilities for each class for a point satisfying the conditions for node i .

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class j if its true class is i .

CutCategories

An n -by-2 cell array of the categories used at branches in `tree`, where n is the number of nodes. For each branch node i based on a categorical predictor variable x , the left child is chosen if x is among the categories listed in `CutCategories{i, 1}`, and the right child is chosen if x is among those listed in `CutCategories{i, 2}`. Both columns of `CutCategories` are empty for branch nodes based on continuous predictors and for leaf nodes.

`CutPoint` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

CutPoint

An n -element vector of the values used as cut points in `tree`, where n is the number of nodes. For each branch node i based on a continuous predictor variable x , the left child is chosen if $x < \text{CutPoint}(i)$ and the right child is chosen if $x \geq \text{CutPoint}(i)$. `CutPoint` is NaN for branch nodes based on categorical predictors and for leaf nodes.

`CutPoint` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

CutType

An n -element cell array indicating the type of cut at each node in `tree`, where n is the number of nodes. For each node i , `CutType{i}` is:

- 'continuous' — If the cut is defined in the form $x < v$ for a variable x and cut point v .
- 'categorical' — If the cut is defined by whether a variable x takes a value in a set of categories.
- '' — If i is a leaf node.

`CutPoint` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

CutVar

An n -element cell array of the names of the variables used for branching in each node in `tree`, where n is the number of nodes. These variables are sometimes known as *cut variables*. For leaf nodes, `CutVar` contains an empty string.

`CutPoint` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

IsBranch

An n -element logical vector that is true for each branch node and false for each leaf node of `tree`.

CompactClassificationTree

NodeClass

An n -element cell array with the names of the most probable classes in each node of `tree`, where n is the number of nodes in the tree. Every element of this array is a string equal to one of the class names in `ClassNames`.

NodeErr

An n -element vector of the errors of the nodes in `tree`, where n is the number of nodes. `NodeErr(i)` is the misclassification probability for node i .

NodeProb

An n -element vector of the probabilities of the nodes in `tree`, where n is the number of nodes. The probability of a node is computed as the proportion of observations from the original data that satisfy the conditions for the node. This proportion is adjusted for any prior probabilities assigned to each class.

NodeSize

An n -element vector of the sizes of the nodes in `tree`, where n is the number of nodes. The size of a node is defined as the number of observations from the data used to create the tree that satisfy the conditions for the node.

NumNodes

The number of nodes in `tree`.

Parent

An n -element vector containing the number of the parent node for each node in `tree`, where n is the number of nodes. The parent of the root node is 0.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in X .

Prior

Prior probabilities for each class. `Prior` is a numeric vector whose entries relate to the corresponding `ClassNames` property.

PruneList

An n -element numeric vector with the pruning levels in each node of `tree`, where n is the number of nodes.

ResponseName

String describing the response variable Y .

Risk

An n -element vector of the risk of the nodes in `tree`, where n is the number of nodes. For each node i ,

$$\text{Risk}(i) = \text{NodeErr}(i) * \text{NodeProb}(i).$$

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$. For a list of built-in transformation functions and the syntax of custom transformation functions, see `ClassificationTree.fit`.

Add or change a `ScoreTransform` function by dot addressing:

```
ctree.ScoreTransform = 'function'  
or  
ctree.ScoreTransform = @function
```

SurrCutCategories

An n -element cell array of the categories used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutCategories{k}` is a cell array. The length of `SurrCutCategories{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutCategories{k}` is either an empty string for a continuous surrogate predictor, or is a two-element cell array with categories

CompactClassificationTree

for a categorical surrogate predictor. The first element of this two-element cell array lists categories assigned to the left child by this surrogate split and the second element of this two-element cell array lists categories assigned to the right child by this surrogate split. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutCategories` contains an empty cell.

SurrCutFlip

An n -element cell array of the numeric cut assignments used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutFlip{k}` is a numeric vector. The length of `SurrCutFlip{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutFlip{k}` is either zero for a categorical surrogate predictor, or a numeric cut assignment for a continuous surrogate predictor. The numeric cut assignment can be either -1 or $+1$. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and the cut assignment for this surrogate split is $+1$, or if $Z \geq C$ and the cut assignment for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and the cut assignment for this surrogate split is $+1$, or if $Z < C$ and the cut assignment for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutFlip` contains an empty array.

SurrCutPoint

An n -element cell array of the numeric values used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutPoint{k}` is a numeric vector. The length of `SurrCutPoint{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutPoint{k}` is either NaN for a categorical surrogate predictor, or a numeric cut for a continuous surrogate predictor. For every surrogate split with a

numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and `SurrCutFlip` for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and `SurrCutFlip` for this surrogate split is $+1$, or if $Z < C$ and `SurrCutFlip` for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables returned by `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutPoint` contains an empty cell.

SurrCutType

An n -element cell array indicating types of surrogate splits at each node in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutType{k}` is a cell array with the types of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutType` contains an empty cell. A surrogate split type can be either 'continuous' if the cut is defined in the form $Z < V$ for a variable Z and cut point V or 'categorical' if the cut is defined by whether Z takes a value in a set of categories.

SurrCutVar

An n -element cell array of the names of the variables used for surrogate splits in each node in `tree`, where n is the number of nodes in `tree`. Every element of `SurrCutVar` is a cell array with the names of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutVar` contains an empty cell.

CompactClassificationTree

SurrVarAssoc

An n -element cell array of the predictive measures of association for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrVarAssoc{k}` is a numeric vector. The length of `SurrVarAssoc{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrVarAssoc{k}` gives the predictive measure of association between the optimal split and this surrogate split. The order of the surrogate split variables at each node is the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrVarAssoc` contains an empty cell.

Methods

<code>edge</code>	Classification edge
<code>loss</code>	Classification error
<code>margin</code>	Classification margins
<code>meanSurrVarAssoc</code>	Mean predictive measure of association for surrogate splits in decision tree
<code>predict</code>	Predict classification
<code>predictorImportance</code>	Estimates of predictor importance
<code>view</code>	View tree

Definitions

Impurity and Node Error

`ClassificationTree` splits nodes based on either *impurity* or *node error*. Impurity means one of several things, depending on your choice of the `SplitCriterion` name-value pair:

- Gini's Diversity Index (`gdi`) — The Gini index of a node is

$$1 - \sum_i p^2(i),$$

where the sum is over the classes i at the node, and $p(i)$ is the observed fraction of classes with class i that reach the node. A node with just one class (a *pure* node) has Gini index 0; otherwise the Gini index is positive. So the Gini index is a measure of node impurity.

- Deviance ('deviance') — With $p(i)$ defined as for the Gini index, the deviance of a node is

$$-\sum_i p(i) \log p(i).$$

A pure node has deviance 0; otherwise, the deviance is positive.

- Twoing rule ('twoing') — Twoing is not a purity measure of a node, but is a different measure for deciding how to split a node. Let $L(i)$ denote the fraction of members of class i in the left child node after a split, and $R(i)$ denote the fraction of members of class i in the right child node after a split. Choose the split criterion to maximize

$$P(L)P(R) \left(\sum_i |L(i) - R(i)| \right)^2,$$

where $P(L)$ and $P(R)$ are the fractions of observations that split to the left and right respectively. If the expression is large, the split made each child node purer. Similarly, if the expression is small, the split made each child node similar to each other, and hence similar to the parent node, and so the split did not increase node purity.

- Node error — The node error is the fraction of misclassified classes at a node. If j is the class with largest number of training samples at a node, the node error is

$$1 - p(j).$$

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

CompactClassificationTree

Examples

Construct a compact classification tree for the Fisher iris data, and compare the size of the resulting tree to that of the original tree:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
ctree = compact(tree);
t = whos('tree'); % t.bytes = size of tree in bytes
c = whos('ctree'); % c.bytes = size of ctree in bytes
[c.bytes t.bytes]

ans =
     6818     13913
```

See Also

[ClassificationTree.fit](#) | [ClassificationTree](#) | [compact](#)

Purpose	Compact regression ensemble class
Description	Compact version of a regression ensemble (of class <code>RegressionEnsemble</code>). The compact version does not include the data for training the regression ensemble. Therefore, you cannot perform some tasks with a compact regression ensemble, such as cross validation. Use a compact regression ensemble for making predictions (regressions) of new data.
Construction	<code>cens = compact(ens)</code> constructs a compact decision ensemble from a full decision ensemble.
	Input Arguments
	ens A regression ensemble created by <code>fitensemble</code> .
Properties	CategoricalPredictors List of categorical predictors. <code>CategoricalPredictors</code> is a numeric vector with indices from 1 to <code>p</code> , where <code>p</code> is the number of columns of <code>X</code> .
	CombineWeights A string describing how the ensemble combines learner predictions.
	NTrained Number of trained learners in the ensemble, a positive scalar.
	PredictorNames A cell array of names for the predictor variables, in the order in which they appear in <code>X</code> .
	ResponseName A string with the name of the response variable <code>Y</code> .
	ResponseTransform

CompactRegressionEnsemble

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$.

Add or change a ResponseTransform function by dot addressing:

```
cens.ResponseTransform = @function
```

Trained

The trained learners, a cell array of compact regression models.

TrainedWeights

A numeric vector of weights the ensemble assigns to its learners. The ensemble computes predicted response by aggregating weighted predictions from its learners.

Methods

loss	Regression error
predict	Predict response of ensemble
predictorImportance	Estimates of predictor importance
removeLearners	Remove members of compact regression ensemble

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Construct a regression ensemble for the carsmall data. Make a compact version of the ensemble, and compare its size to that of the full ensemble:

```
load carsmall
learner = RegressionTree.template('MinParent',20);
ens = fitensemble([Weight, Cylinders],MPG,...
    'LSBoost',100,learner,'PredictorNames',{'W','C'},...
    'categoricalpredictors',2);
```

```
cens = compact(ens);  
ee = whos('ens'); % ee.bytes = size of ensemble in bytes  
cee = whos('cens');  
[ee.bytes cee.bytes]
```

```
ans =  
    606903    587096
```

See Also

[fitensemble](#) | [RegressionEnsemble](#) | [predict](#) | [compact](#)

CompactRegressionTree

Purpose Compact regression tree

Description Compact version of a regression tree (of class `RegressionTree`). The compact version does not include the data for training the regression tree. Therefore, you cannot perform some tasks with a compact regression tree, such as cross validation. Use a compact regression tree for making predictions (regressions) of new data.

Construction `ctree = compact(tree)` constructs a compact decision tree from a full decision tree.

Input Arguments

tree

A decision tree constructed by `RegressionTree.fit`.

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to p , where p is the number of columns of X .

CatSplit

An n -by-2 cell array, where n is the number of categorical splits in `tree`. Each row in `CatSplit` gives left and right values for a categorical split. For each branch node with categorical split j based on a categorical predictor variable z , the left child is chosen if z is in `CatSplit(j,1)` and the right child is chosen if z is in `CatSplit(j,2)`. The splits are in the same order as nodes of the tree. Nodes for these splits can be found by running `cuttype` and selecting 'categorical' cuts from top to bottom.

Children

An n -by-2 array containing the numbers of the child nodes for each node in `tree`, where n is the number of nodes. Leaf nodes have child node 0.

CutCategories

An n -by-2 cell array of the categories used at branches in `tree`, where n is the number of nodes. For each branch node i based on a categorical predictor variable x , the left child is chosen if x is among the categories listed in `CutCategories{i,1}`, and the right child is chosen if x is among those listed in `CutCategories{i,2}`. Both columns of `CutCategories` are empty for branch nodes based on continuous predictors and for leaf nodes.

`CutVar` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

CutPoint

An n -element vector of the values used as cut points in `tree`, where n is the number of nodes. For each branch node i based on a continuous predictor variable x , the left child is chosen if `CutPoint < v(i)` and the right child is chosen if `x >= CutPoint(i)`. `CutPoint` is NaN for branch nodes based on categorical predictors and for leaf nodes.

CutType

An n -element cell array indicating the type of cut at each node in `tree`, where n is the number of nodes. For each node i , `CutType{i}` is:

- 'continuous' — If the cut is defined in the form $x < v$ for a variable x and cut point v .
- 'categorical' — If the cut is defined by whether a variable x takes a value in a set of categories.
- '' — If i is a leaf node.

`CutVar` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

CutVar

An n -element cell array of the names of the variables used for branching in each node in `tree`, where n is the number of nodes.

CompactRegressionTree

These variables are sometimes known as *cut variables*. For leaf nodes, `CutVar` contains an empty string.

`CutVar` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

IsBranch

An n -element logical vector `ib` that is `true` for each branch node and `false` for each leaf node of `tree`.

NodeErr

An n -element vector `e` of the errors of the nodes in `tree`, where n is the number of nodes. `e(i)` is the misclassification probability for node `i`.

NodeMean

An n -element numeric array with mean values in each node of `tree`, where n is the number of nodes in the tree. Every element in `NodeMean` is the average of the true `Y` values over all observations in the node.

NodeProb

An n -element vector `p` of the probabilities of the nodes in `tree`, where n is the number of nodes. The probability of a node is computed as the proportion of observations from the original data that satisfy the conditions for the node. This proportion is adjusted for any prior probabilities assigned to each class.

NodeSize

An n -element vector `sizes` of the sizes of the nodes in `tree`, where n is the number of nodes. The size of a node is defined as the number of observations from the data used to create the tree that satisfy the conditions for the node.

NumNodes

The number of nodes n in `tree`.

Parent

An n -element vector p containing the number of the parent node for each node in `tree`, where n is the number of nodes. The parent of the root node is 0.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in X .

PruneList

An n -element numeric vector with the pruning levels in each node of `tree`, where n is the number of nodes.

ResponseName

Name of the response variable Y , a string.

ResponseTransform

Function handle for transforming the raw response values (mean squared error). The function handle should accept a matrix of response values and return a matrix of the same size. The default string 'none' means $@(x)x$, or no transformation.

Add or change a ResponseTransform function by dot addressing:

```
ctree.ResponseTransform = @function
```

Risk

An n -element vector r of the risk of the nodes in `tree`, where n is the number of nodes. The risk $r(i)$ for node i is the node error `NodeErr(i)` multiplied by the node probability `NodeProb(i)`.

SurrCutCategories

An n -element cell array of the categories used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutCategories{k}` is a cell array. The length of `SurrCutCategories{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutCategories{k}` is either an empty string for a continuous

surrogate predictor, or is a two-element cell array with categories for a categorical surrogate predictor. The first element of this two-element cell array lists categories assigned to the left child by this surrogate split, and the second element of this two-element cell array lists categories assigned to the right child by this surrogate split. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutCategories` contains an empty cell.

SurrCutFlip

An n -element cell array of the numeric cut assignments used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutFlip{k}` is a numeric vector. The length of `SurrCutFlip{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutFlip{k}` is either zero for a categorical surrogate predictor, or a numeric cut assignment for a continuous surrogate predictor. The numeric cut assignment can be either -1 or $+1$. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and the cut assignment for this surrogate split is $+1$, or if $Z \geq C$ and the cut assignment for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and the cut assignment for this surrogate split is $+1$, or if $Z < C$ and the cut assignment for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutFlip` contains an empty array.

SurrCutPoint

An n -element cell array of the numeric values used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutPoint{k}` is a numeric vector. The length of `SurrCutPoint{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutPoint{k}` is either NaN for a categorical surrogate predictor, or a numeric cut for a

continuous surrogate predictor. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and `SurrCutFlip` for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and `SurrCutFlip` for this surrogate split is $+1$, or if $Z < C$ and `SurrCutFlip` for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables returned by `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutPoint` contains an empty cell.

SurrCutType

An n -element cell array indicating types of surrogate splits at each node in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutType{k}` is a cell array with the types of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutType` contains an empty cell. A surrogate split type can be either 'continuous' if the cut is defined in the form $Z < V$ for a variable Z and cut point V or 'categorical' if the cut is defined by whether Z takes a value in a set of categories.

SurrCutVar

An n -element cell array of the names of the variables used for surrogate splits in each node in `tree`, where n is the number of nodes in `tree`. Every element of `SurrCutVar` is a cell array with the names of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutVar` contains an empty cell.

CompactRegressionTree

SurrVarAssoc

An n -element cell array of the predictive measures of association for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrVarAssoc{k}` is a numeric vector. The length of `SurrVarAssoc{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrVarAssoc{k}` gives the predictive measure of association between the optimal split and this surrogate split. The order of the surrogate split variables at each node is the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrVarAssoc` contains an empty cell.

Methods

<code>loss</code>	Regression error
<code>meanSurrVarAssoc</code>	Mean predictive measure of association for surrogate splits in decision tree
<code>predict</code>	Predict response of regression tree
<code>predictorImportance</code>	Estimates of predictor importance
<code>view</code>	View tree

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Construct a regression tree for the `carsmall` data. Make a compact version of the tree, and compare its size to that of the full tree:

```
load carsmall
tree = RegressionTree.fit([Weight, Cylinders],MPG,...
    'MinParent',20,...
    'PredictorNames',{'W','C'});
ctree = compact(tree);
t = whos('tree'); % t.bytes = size of tree in bytes
```

```
c = whos('ctree'); % c.bytes = size of ctrees in bytes  
[c.bytes t.bytes]
```

```
ans =  
      4972      8173
```

See Also

[RegressionTree.fit](#) | [RegressionTree](#) | [compact](#)

CompactTreeBagger

Purpose Compact ensemble of decision trees grown by bootstrap aggregation

Description CompactTreeBagger class is a lightweight class that contains the trees grown using TreeBagger. CompactTreeBagger does not preserve any information about how TreeBagger grew the decision trees. It does not contain the input data used for growing trees, nor does it contain training parameters such as minimal leaf size or number of variables sampled for each decision split at random. You can only use CompactTreeBagger for predicting the response of the trained ensemble given new data X , and other related functions.

CompactTreeBagger lets you save the trained ensemble to disk, or use it in any other way, while discarding training data and various parameters of the training configuration irrelevant for predicting response of the fully grown ensemble. This reduces storage and memory requirements, especially for ensembles trained on large data sets.

Construction CompactTreeBagger Create CompactTreeBagger object

Methods

combine	Combine two ensembles
error	Error (misclassification probability or MSE)
margin	Classification margin
mdsProx	Multidimensional scaling of proximity matrix
meanMargin	Mean classification margin
outlierMeasure	Outlier measure for data
predict	Predict response

proximity	Proximity matrix for data
setDefaultYfit	Set default value for predict

Properties

ClassNames

The `ClassNames` property is a cell array containing the class names for the response variable `Y` supplied to `TreeBagger`. This property is empty for regression trees.

DeltaCritDecisionSplit

The `DeltaCritDecisionSplit` property is a numeric array of size 1-by-`Nvars` of changes in the split criterion summed over splits on each variable, averaged across the entire ensemble of grown trees.

See also `TreeBagger.DeltaCritDecisionSplit`, `classregtree.varimportance`

DefaultYfit

The `DefaultYfit` property controls what predicted value `CompactTreeBagger` returns when no prediction is possible, for example when the `predict` method needs to predict for an observation which has only false values in the matrix supplied through `'useifort'` argument.

For classification, you can set this property to either `' '` or `'MostPopular'`. If you choose `'MostPopular'` (default), the property value becomes the name of the most probable class in the training data.

For regression, you can set this property to any numeric scalar. The default is the mean of the response for the training data.

See also `predict`, `setDefaultYfit`, `TreeBagger.DefaultYfit`.

Method

The `Method` property is `'classification'` for classification ensembles and `'regression'` for regression ensembles.

CompactTreeBagger

NTrees

The `NTrees` property is a scalar equal to the number of decision trees in the ensemble.

NVarSplit

The `NVarSplit` property is a numeric array of size 1-by-*Nvars*, where every element gives a number of splits on this predictor summed over all trees.

Trees

The `Trees` property is a cell array of size `NTrees`-by-1 containing the trees in the ensemble.

VarAssoc

The `VarAssoc` property is a matrix of size *Nvars*-by-*Nvars* with predictive measures of variable association, averaged across the entire ensemble of grown trees. If you grew the ensemble setting 'surrogate' to 'on', this matrix for each tree is filled with predictive measures of association averaged over the surrogate splits. If you grew the ensemble setting 'surrogate' to 'off' (default), `VarAssoc` is diagonal.

See also `classregtree.MeanSurrVarAssoc`

VarNames

The `VarNames` property is a cell array containing the names of the predictor variables (features). These names are taken from the optional 'names' parameter that supplied to `TreeBagger`. The default names are 'x1', 'x2', etc.

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

See Also

`classregtree`

How To

- “Ensemble Methods” on page 13-54
- “Classification Trees and Regression Trees” on page 13-30
- “Grouping Variables” on page 2-72

CompactTreeBagger

Purpose Create CompactTreeBagger object

Description When you use the TreeBagger constructor to grow trees, it creates a CompactTreeBagger object. You can obtain the compact object from the full TreeBagger object using the TreeBagger/compact method. You do not create an instance of CompactTreeBagger directly.

See Also TreeBagger

How To

- “Grouping Variables” on page 2-72
- “Ensemble Methods” on page 13-54

TreeBagger.ComputeOOBPrediction property

Purpose

Flag to compute out-of-bag predictions

Description

The ComputeOOBPrediction property is a logical flag specifying whether out-of-bag predictions for training observations should be computed. The default is `false`.

If this flag is true, the following properties are available:

- `OOBIndices`
- `OOBInstanceWeight`

If this flag is true, the following methods can be called:

- `oobError`
- `oobMargin`
- `oobMeanMargin`

See Also

`oobError` | `OOBIndices` | `OOBInstanceWeight` | `oobMargin` | `oobMeanMargin`

TreeBagger.ComputeOOBVarImp property

Purpose Flag to compute out-of-bag variable importance

Description The ComputeOOBVarImp property is a logical flag specifying whether TreeBagger should compute out-of-bag estimates of variable importance. The default is false.

If this flag is true, the following properties are available:

- OOBPermutedVarDeltaError
- OOBPermutedVarDeltaMeanMargin
- OOBPermutedVarCountRaiseMargin

See Also ComputeOOBPrediction | OOBPermutedVarDeltaError | OOBPermutedVarDeltaMeanMargin | OOBPermutedVarCountRaiseMargin | oobMeanMargin | TreeBagger

Purpose

Confusion matrix

Syntax

```
C = confusionmat(group,grouphat)
C = confusionmat(group,grouphat,'order',groupporder)
[C,order] = confusionmat(...)
```

Description

`C = confusionmat(group,grouphat)` returns the confusion matrix `C` determined by the known and predicted groups in `group` and `grouphat`, respectively. `group` and `grouphat` are grouping variables with the same number of observations, as described in “Grouping Variables” on page 2-72. Input vectors must be of the same type. `C` is a square matrix with size equal to the total number of distinct elements in `group` and `grouphat`. `C(i,j)` is a count of observations known to be in group `i` but predicted to be in group `j`. Group indices and their order are the same for the rows and columns of `C`, computed by `grp2idx` using `grp2idx(group;grouphat)`. NaN, empty, or 'undefined' groups are not counted.

`C = confusionmat(group,grouphat,'order',groupporder)` uses `groupporder` to order the rows and columns of `C`. `groupporder` is a grouping variable containing all of the distinct elements in `group` and `grouphat`. If `groupporder` contains elements that are not in `group` or `grouphat`, the corresponding entries in `C` will be 0.

`[C,order] = confusionmat(...)` also returns the order of the rows and columns of `C` in a variable `order` the same type as `group` and `grouphat`.

Examples

Example 1

Display the confusion matrix for data with two misclassifications and one missing classification:

```
g1 = [1 1 2 2 3 3]'; % Known groups
g2 = [1 1 2 3 4 NaN]'; % Predicted groups
```

```
[C,order] = confusionmat(g1,g2)
C =
```

```
    2    0    0    0
    0    1    1    0
    0    0    0    1
    0    0    0    0
order =
    1
    2
    3
    4
```

Example 2

Randomize the measurements and groups in Fisher's iris data:

```
load fisheriris
numObs = length(species);
p = randperm(numObs);
meas = meas(p,:);
species = species(p);
```

Use `classify` to classify measurements in the second half of the data, using the first half of the data for training:

```
half = floor(numObs/2);
training = meas(1:half,:);
trainingSpecies = species(1:half);
sample = meas(half+1:end,:);
grouphat = classify(sample,training,trainingSpecies);
```

Display the confusion matrix for the resulting classification:

```
group = species(half+1:end);
[C,order] = confusionmat(group,grouphat)
C =
    22    0    0
     2   22    0
     0    0   29
order =
    'virginica'
```



```
'versicolor'  
'setosa'
```

See Also

`crosstab` | `grp2idx`

How To

- “Grouping Variables” on page 2-72

controlchart

Purpose Shewhart control charts

Syntax

```
controlchart(X)
controlchart(x,group)
controlchart(X,group)
[stats,plotdata] = controlchart(x,[group])
controlchart(x,group,'name',value)
```

Description `controlchart(X)` produces an xbar chart of the measurements in matrix *X*. Each row of *X* is considered to be a subgroup of measurements containing replicate observations taken at the same time. The rows should be in time order. If *X* is a time series object, the time samples should contain replicate observations.

The chart plots the means of the subgroups in time order, a center line (CL) at the average of the means, and upper and lower control limits (UCL, LCL) at three standard errors from the center line. The standard error is the estimated process standard deviation divided by the square root of the subgroup size. Process standard deviation is estimated from the average of the subgroup standard deviations. Out of control measurements are marked as violations and drawn with a red circle. Data cursor mode is enabled, so clicking any data point displays information about that point.

`controlchart(x,group)` accepts a grouping variable `group` for a vector of measurements `x`. `group` is a categorical variable, vector, string array, or cell array of strings the same length as `x`. Consecutive measurements `x(n)` sharing the same value of `group(n)` for $1 \leq n \leq \text{length}(x)$ are defined to be a subgroup. Subgroups can have different numbers of observations.

`controlchart(X,group)` accepts a grouping variable `group` for a matrix of measurements in *X*. In this case, `group` is only used to label the time axis; it does not change the default grouping by rows.

`[stats,plotdata] = controlchart(x,[group])` returns a structure `stats` of subgroup statistics and parameter estimates, and a structure `plotdata` of plotted values. `plotdata` contains one record for each chart.

The fields in `stats` and `plotdata` depend on the chart type.

The fields in `stats` are selected from the following:

- `mean` — Subgroup means
- `std` — Subgroup standard deviations
- `range` — Subgroup ranges
- `n` — Subgroup size, or total inspection size or area
- `i` — Individual data values
- `ma` — Moving averages
- `mr` — Moving ranges
- `count` — Count of defects or defective items
- `mu` — Estimated process mean
- `sigma` — Estimated process standard deviation
- `p` — Estimated proportion defective
- `m` — Estimated mean defects per unit

The fields in `plotdata` are the following:

- `pts` — Plotted point values
- `cl` — Center line
- `lcl` — Lower control limit
- `ucl` — Upper control limit
- `se` — Standard error of plotted point
- `n` — Subgroup size
- `ooc` — Logical that is true for points that are out of control

`controlchart(x,group,'name',value)` specifies one or more of the following optional parameter name/value pairs, with *name* in single quotes:

controlchart

- `charttype` — The name of a chart type chosen from among the following:
 - `'xbar'` — Xbar or mean
 - `'s'` — Standard deviation
 - `'r'` — Range
 - `'ewma'` — Exponentially weighted moving average
 - `'i'` — Individual observation
 - `'mr'` — Moving range of individual observations
 - `'ma'` — Moving average of individual observations
 - `'p'` — Proportion defective
 - `'np'` — Number of defectives
 - `'u'` — Defects per unit
 - `'c'` — Count of defects

Alternatively, a parameter can be a cell array listing multiple compatible chart types. There are four sets of compatible types:

- `'xbar', 's', 'r', and 'ewma'`
 - `'i', 'mr', and 'ma'`
 - `'p' and 'np'`
 - `'u' and 'c'`
- `display` — Either `'on'` (default) to display the control chart, or `'off'` to omit the display
 - `label` — A string array or cell array of strings, one per subgroup. This label is displayed as part of the data cursor for a point on the plot.
 - `lambda` — A parameter between 0 and 1 controlling how much the current prediction is influenced by past observations in an EWMA

plot. Higher values of 'lambda' give less weight to past observations and more weight to the current observation. The default is 0.4.

- **limits** — A three-element vector specifying the values of the lower control limit, center line, and upper control limits. Default is to estimate the center line and to compute control limits based on the estimated value of sigma. Not permitted if there are multiple chart types.
- **mean** — Value for the process mean, or an empty value (default) to estimate the mean from \bar{X} . This is the μ parameter for \bar{p} and $n\bar{p}$ charts, the mean defects per unit for \bar{u} and \bar{c} charts, and the normal μ parameter for other charts.
- **nsigma** — The number of sigma multiples from the center line to a control limit. Default is 3.
- **parent** — The handle of the axes to receive the control chart plot. Default is to create axes in a new figure. Not permitted if there are multiple chart types.
- **rules** — The name of a control rule, or a cell array containing multiple control rule names. These rules, together with the control limits, determine if a point is marked as out of control. The default is to apply no control rules, and to use only the control limits to decide if a point is out of control. See `controlrules` for more information. Control rules are applied to charts that measure the process level (\bar{x} , \bar{i} , \bar{c} , \bar{u} , \bar{p} , and $n\bar{p}$) rather than the variability (\bar{r} , \bar{s}), and they are not applied to charts based on moving statistics (\bar{m} , $m\bar{r}$, \bar{ewma}).
- **sigma** — Either a value for sigma, or a method of estimating sigma chosen from among 'std' (the default) to use the average within-subgroup standard deviation, 'range' to use the average subgroup range, and 'variance' to use the square root of the pooled variance. When creating \bar{i} , $m\bar{r}$, or \bar{m} charts for data not in subgroups, the estimate is always based on a moving range.
- **specs** — A vector specifying specification limits. Typically this is a two-element vector of lower and upper specification limits. Since specification limits typically apply to individual measurements, this

controlchart

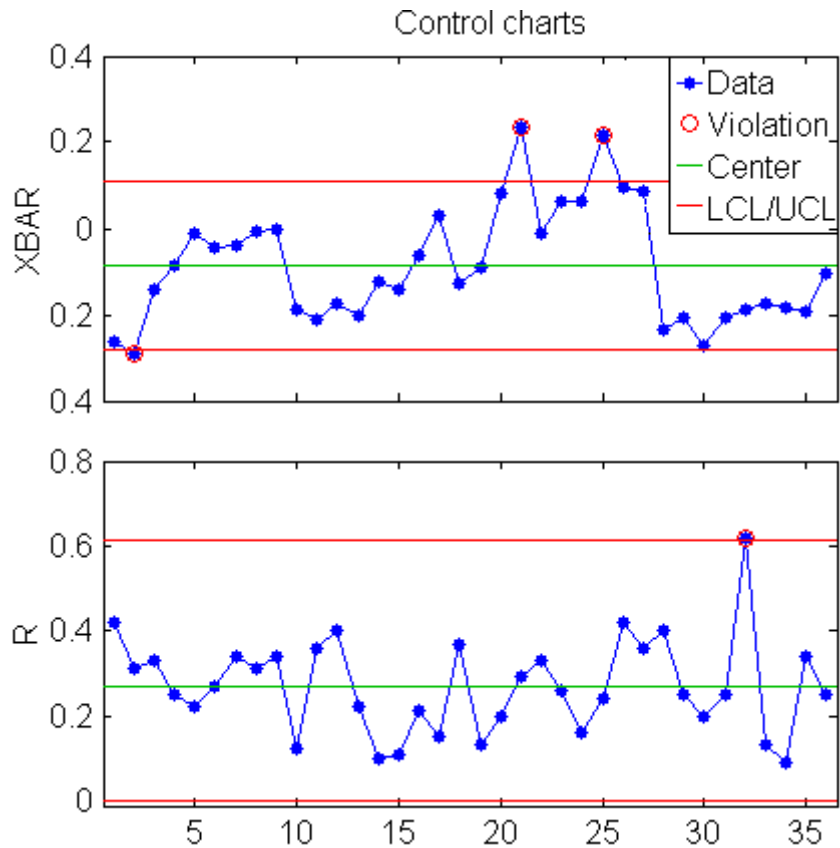
parameter is primarily suitable for *i* charts. These limits are not plotted on *r*, *s*, or *mr* charts.

- `unit` — The total number of inspected items for *p* and *np* charts, and the size of the inspected unit for *u* and *c* charts. In both cases *X* must be the count of the number of defects or defectives found. Default is 1 for *u* and *c* charts. This argument is required (no default) for *p* and *np* charts.
- `width` — The width of the window used for computing the moving ranges and averages in *mr* and *ma* charts, and for computing the sigma estimate in *i*, *mr*, and *ma* charts. Default is 5.

Examples

Create *xbar* and *r* control charts for the data in `parts.mat`:

```
load parts
st = controlchart(runout, 'chart', {'xbar' 'r'});
```



Display the process mean and standard deviation:

```
fprintf('Parameter estimates: mu = %g, sigma = %g\n',st.mu,st.sigma);
Parameter estimates: mu = -0.0863889, sigma = 0.130215
```

See Also

controlrules

How To

- “Grouping Variables” on page 2-72

controlrules

Purpose Western Electric and Nelson control rules

Syntax
`R = controlrules('rules',x,c1,se)`
`[R,RULES] = controlrules('rules',x,c1,se)`

Description `R = controlrules('rules',x,c1,se)` determines which points in the vector `x` violate the control rules in `rules`. `c1` is a vector of center-line values. `se` is a vector of standard errors. (Typically, control limits on a control chart are at the values `c1 - 3*se` and `c1 + 3*se`.) `rules` is the name of a control rule, or a cell array containing multiple control rule names, from the list below. If `x` has n values and `rules` contains m rules, then `R` is an n -by- m logical array, with `R(i, j)` assigned the value 1 if point i violates rule j , 0 if it does not.

The following are accepted values for `rules` (specified inside single quotes):

- `we1` — 1 point above `c1 + 3*se`
- `we2` — 2 of 3 above `c1 + 2*se`
- `we3` — 4 of 5 above `c1 + se`
- `we4` — 8 of 8 above `c1`
- `we5` — 1 below `c1 - 3*se`
- `we6` — 2 of 3 below `c1 - 2*se`
- `we7` — 4 of 5 below `c1 - se`
- `we8` — 8 of 8 below `c1`
- `we9` — 15 of 15 between `c1 - se` and `c1 + se`
- `we10` — 8 of 8 below `c1 - se` or above `c1 + se`
- `n1` — 1 point below `c1 - 3*se` or above `c1 + 3*se`
- `n2` — 9 of 9 on the same side of `c1`
- `n3` — 6 of 6 increasing or decreasing
- `n4` — 14 alternating up/down

- n5 — 2 of 3 below $c1 - 2*se$ or above $c1 + 2*se$, same side
- n6 — 4 of 5 below $c1 - se$ or above $c1 + se$, same side
- n7 — 15 of 15 between $c1 - se$ and $c1 + se$
- n8 — 8 of 8 below $c1 - se$ or above $c1 + se$, either side
- we — All Western Electric rules
- n — All Nelson rules

For multi-point rules, a rule violation at point i indicates that the set of points ending at point i triggered the rule. Point i is considered to have violated the rule only if it is one of the points violating the rule's condition.

Any points with NaN as their x , $c1$, or se values are not considered to have violated rules, and are not counted in the rules for other points.

Control rules can be specified in the `controlchart` function as values for the 'rules' parameter.

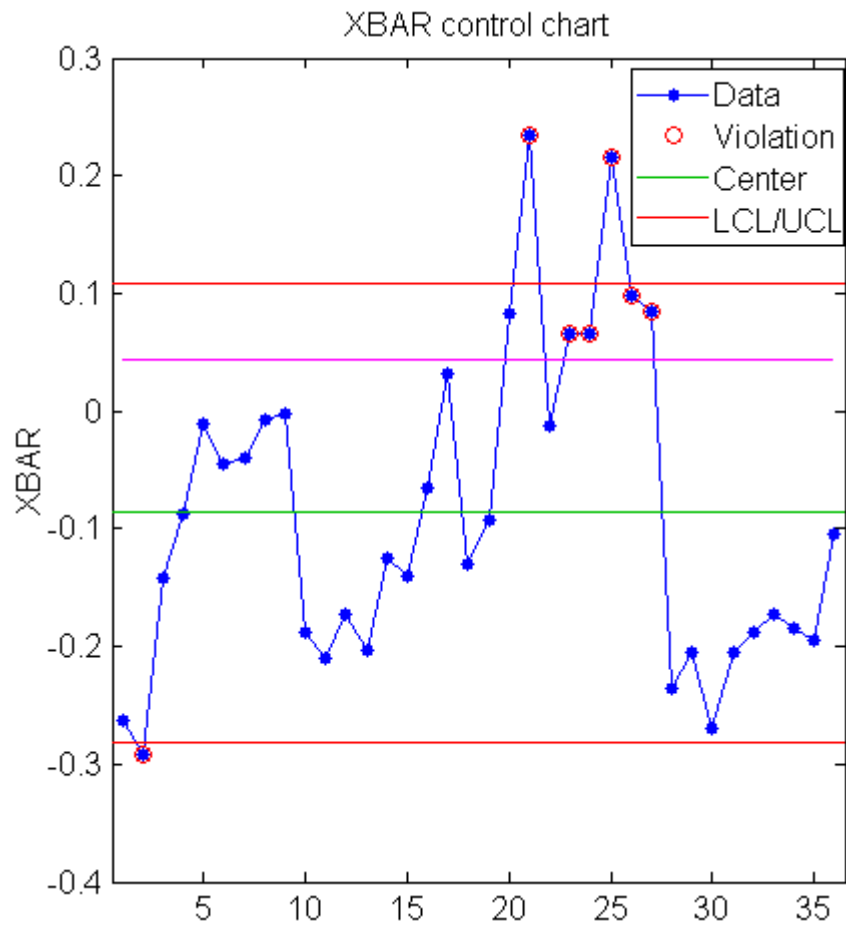
`[R,RULES] = controlrules('rules',x,c1,se)` returns a cell array of text strings `RULES` listing the rules applied.

Examples

Create an xbar chart using the `we2` rule to mark out of control measurements:

```
load parts;
st = controlchart(runout, 'rules', 'we2');
x = st.mean;
c1 = st.mu;
se = st.sigma./sqrt(st.n);
hold on
plot(c1+2*se, 'm')
```

controlrules



Use controlrules to identify the measurements that violate the control rule:

```
R = controlrules('we2',x,c1,se);  
I = find(R)  
I =  
    21  
    23
```

24
25
26
27

See Also controlchart

gmdistribution.Converged property

Purpose Determine if algorithm converged

Description Logical true if the algorithm has converged; logical false if the algorithm has not converged.

Note This property applies only to gmdistribution objects constructed with `fit`.

Purpose Cophenetic correlation coefficient

Syntax `c = cophenet(Z,Y)`
`[c,d] = cophenet(Z,Y)`

Description `c = cophenet(Z,Y)` computes the cophenetic correlation coefficient for the hierarchical cluster tree represented by `Z`. `Z` is the output of the linkage function. `Y` contains the distances or dissimilarities used to construct `Z`, as output by the `pdist` function. `Z` is a matrix of size $(m-1)$ -by-3, with distance information in the third column. `Y` is a vector of size $m*(m-1)/2$.

`[c,d] = cophenet(Z,Y)` returns the cophenetic distances `d` in the same lower triangular distance vector format as `Y`.

The cophenetic correlation for a cluster tree is defined as the linear correlation coefficient between the cophenetic distances obtained from the tree, and the original distances (or dissimilarities) used to construct the tree. Thus, it is a measure of how faithfully the tree represents the dissimilarities among observations.

The cophenetic distance between two observations is represented in a dendrogram by the height of the link at which those two observations are first joined. That height is the distance between the two subclusters that are merged by that link.

The output value, `c`, is the cophenetic correlation coefficient. The magnitude of this value should be very close to 1 for a high-quality solution. This measure can be used to compare alternative cluster solutions obtained using different algorithms.

The cophenetic correlation between `Z(:,3)` and `Y` is defined as

$$c = \frac{\sum_{i < j} (Y_{ij} - y)(Z_{ij} - z)}{\sqrt{\sum_{i < j} (Y_{ij} - y)^2 \sum_{i < j} (Z_{ij} - z)^2}}$$

where:

- Y_{ij} is the distance between objects i and j in `Y`.

cophenet

- Z_{ij} is the cophenetic distance between objects i and j , from $Z(:,3)$.
- y and z are the average of Y and $Z(:,3)$, respectively.

Examples

```
X = [rand(10,3); rand(10,3)+1; rand(10,3)+2];
Y = pdist(X);
Z = linkage(Y, 'average');

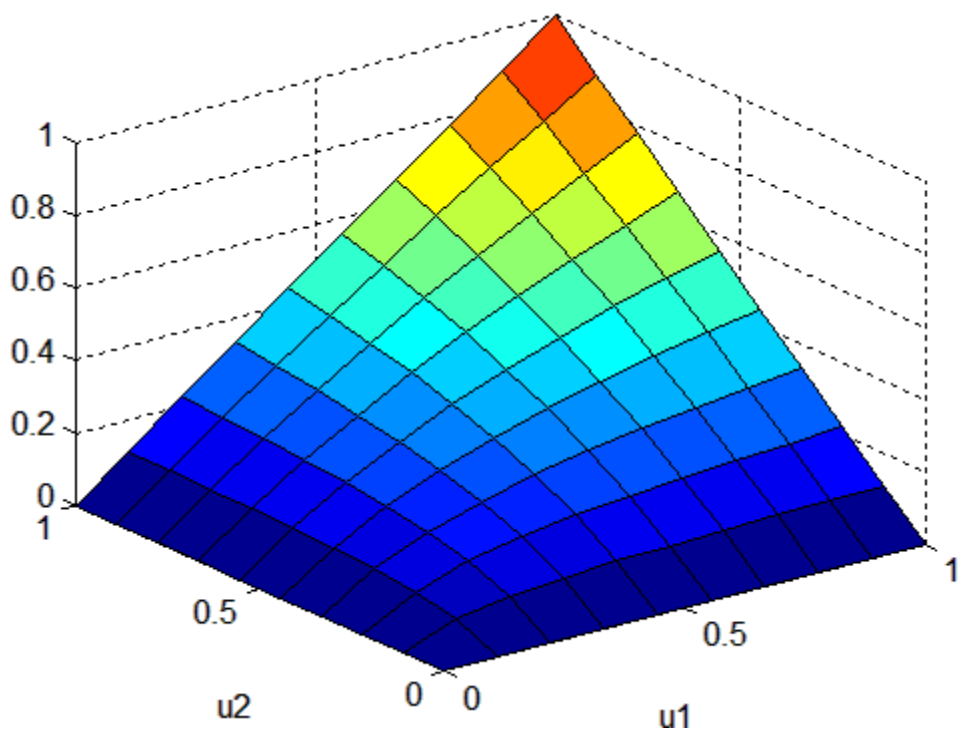
% Compute Spearman's rank correlation between the
% dissimilarities and the cophenetic distances
[c,D] = cophenet(Z,Y);
r = corr(Y',D', 'type', 'spearman')
r =
    0.8279
```

See Also

```
cluster | dendrogram | inconsistent | linkage | pdist |
squareform
```

Purpose	Copula cumulative distribution function
Syntax	<pre>Y = copulacdf('Gaussian',U,rho) Y = copulacdf('t',U,rho,NU) Y = copulacdf('family',U,alpha)</pre>
Description	<p><code>Y = copulacdf('Gaussian',U,rho)</code> returns the cumulative probability of the Gaussian copula with linear correlation parameters <code>rho</code>, evaluated at the points in <code>U</code>. <code>U</code> is an <code>n</code>-by-<code>p</code> matrix of values in <code>[0,1]</code>, representing <code>n</code> points in the <code>p</code>-dimensional unit hypercube. <code>rho</code> is a <code>p</code>-by-<code>p</code> correlation matrix. If <code>U</code> is an <code>n</code>-by-2 matrix, <code>rho</code> may also be a scalar correlation coefficient.</p> <p><code>Y = copulacdf('t',U,rho,NU)</code> returns the cumulative probability of the <code>t</code> copula with linear correlation parameters <code>rho</code> and degrees of freedom parameter <code>NU</code>, evaluated at the points in <code>U</code>. <code>U</code> is an <code>n</code>-by-<code>p</code> matrix of values in <code>[0,1]</code>. <code>rho</code> is a <code>p</code>-by-<code>p</code> correlation matrix. If <code>U</code> is an <code>n</code>-by-2 matrix, <code>rho</code> may also be a scalar correlation coefficient.</p> <p><code>Y = copulacdf('family',U,alpha)</code> returns the cumulative probability of the bivariate Archimedean copula determined by <code>family</code>, with scalar parameter <code>alpha</code>, evaluated at the points in <code>U</code>. <code>family</code> is Clayton, Frank, or Gumbel. <code>U</code> is an <code>n</code>-by-2 matrix of values in <code>[0,1]</code>.</p>
Examples	<pre>u = linspace(0,1,10); [U1,U2] = meshgrid(u,u); F = copulacdf('Clayton',[U1(:) U2(:)],1); surf(U1,U2,reshape(F,10,10)) xlabel('u1') ylabel('u2')</pre>

copulacdf



See Also

[copulapdf](#) | [copularnd](#) | [copulastat](#) | [copulaparam](#)

Purpose

Fit copula to data

Syntax

```
RHOHAT = copulafit('Gaussian',U)
[RHOHAT,nuhat] = copulafit('t',U)
[RHOHAT,nuhat,nuci] = copulafit('t',U)
paramhat = copulafit('family',U)
[paramhat,paramci] = copulafit('family',U)
[...] = copulafit(...,'alpha',alpha)
[...] = copulafit('t',U,'Method','ApproximateML')
[...] = copulafit(...,'Options',options)
```

Description

`RHOHAT = copulafit('Gaussian',U)` returns an estimate `RHOHAT` of the matrix of linear correlation parameters for a Gaussian copula, given data in `U`. `U` is an n -by- p matrix of values in the open interval $(0,1)$ representing n points in the p -dimensional unit hypercube.

`[RHOHAT,nuhat] = copulafit('t',U)` returns an estimate `RHOHAT` of the matrix of linear correlation parameters for a t copula and an estimate `nuhat` of the degrees of freedom parameter, given data in `U`. `U` is an n -by- p matrix of values in the open interval $(0,1)$ representing n points in the p -dimensional unit hypercube.

`[RHOHAT,nuhat,nuci] = copulafit('t',U)` also returns an approximate 95% confidence interval `nuci` for the degrees of freedom parameter estimated in `nuhat`.

`paramhat = copulafit('family',U)` returns an estimate `paramhat` of the copula parameter for an Archimedean copula specified by `family`, given data in `U`. `U` is an n -by-2 matrix of values in the open interval $(0,1)$ representing n points in the unit square. `family` is one of Clayton, Frank, or Gumbel.

`[paramhat,paramci] = copulafit('family',U)` also returns an approximate 95% confidence interval `paramci` for the copula parameter estimated in `paramhat`.

`[...] = copulafit(...,'alpha',alpha)` returns approximate $100 \times (1 - \alpha)\%$ confidence intervals in `nuci` or `paramci`.

Note By default, `copulafit` uses maximum likelihood to fit a copula to `U`. When `U` contains data transformed to the unit hypercube by parametric estimates of their marginal cumulative distribution functions, this is known as the *Inference Functions for Margins (IFM)* method. When `U` contains data transformed by the empirical cdf (see `ecdf`), this is known as *Canonical Maximum Likelihood (CML)*.

`[...] = copulafit('t',U,'Method','ApproximateML')` fits a t copula for large samples `U` by maximizing an objective function that approximates the profile log-likelihood for the degrees of freedom parameter (see [1]). This method can be significantly faster than maximum likelihood, but the estimates and confidence limits may not be accurate for small to moderate sample sizes.

`[...] = copulafit(...,'Options',options)` specifies control parameters for the iterative parameter estimation algorithm using an options structure `options` as created by `statset`. Type `statset('copulafit')` at the command prompt for fields and default values used by `copulafit`. This argument is not applicable to the 'Gaussian' family.

References

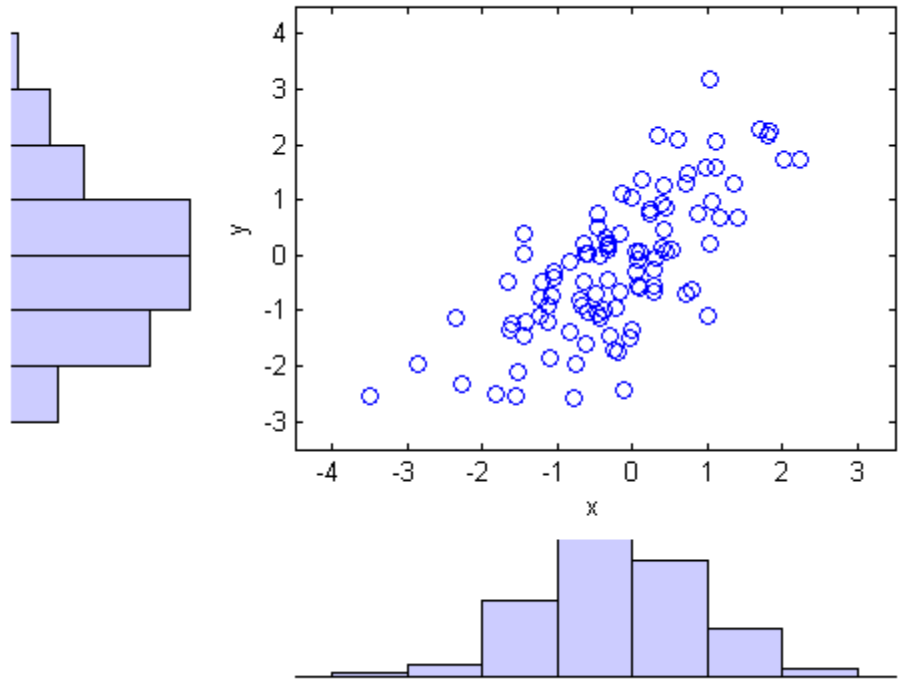
[1] Bouye, E., V. Durrleman, A. Nikeghbali, G. Riboulet, and T. Roncalli. "Copulas for Finance: A Reading Guide and Some Applications." Working Paper. Groupe de Recherche Operationnelle, Credit Lyonnais, 2000.

Examples

Load and plot simulated stock return data:

```
load stockreturns
x = stocks(:,1);
y = stocks(:,2);

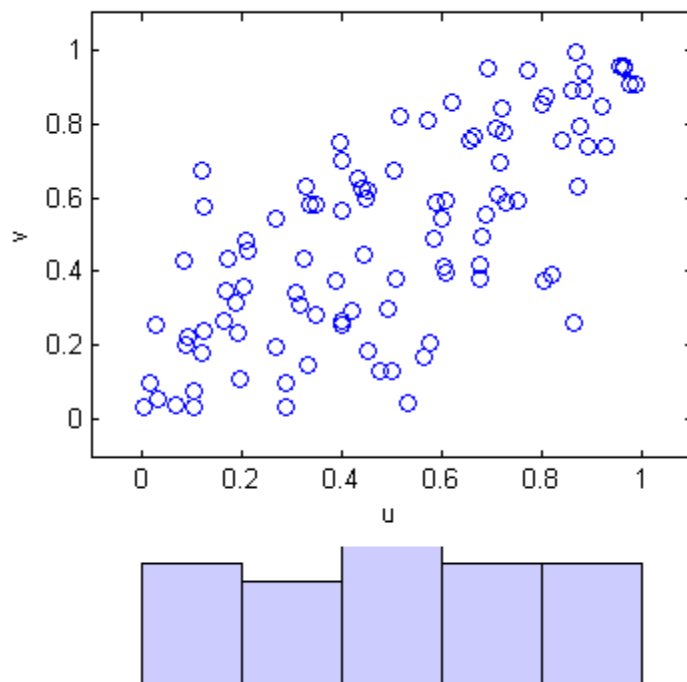
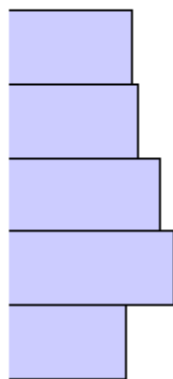
scatterhist(x,y)
```



Transform the data to the copula scale (unit square) using a kernel estimator of the cumulative distribution function:

```
u = ksdensity(x,x,'function','cdf');
v = ksdensity(y,y,'function','cdf');

scatterhist(u,v)
xlabel('u')
ylabel('v')
```



Fit a t copula:

```
[Rho,nu] = copulafit('t',[u v],'Method','ApproximateML')  
Rho =  
    1.0000    0.7220  
    0.7220    1.0000  
nu =  
    2.8934e+006
```

Generate a random sample from the t copula:

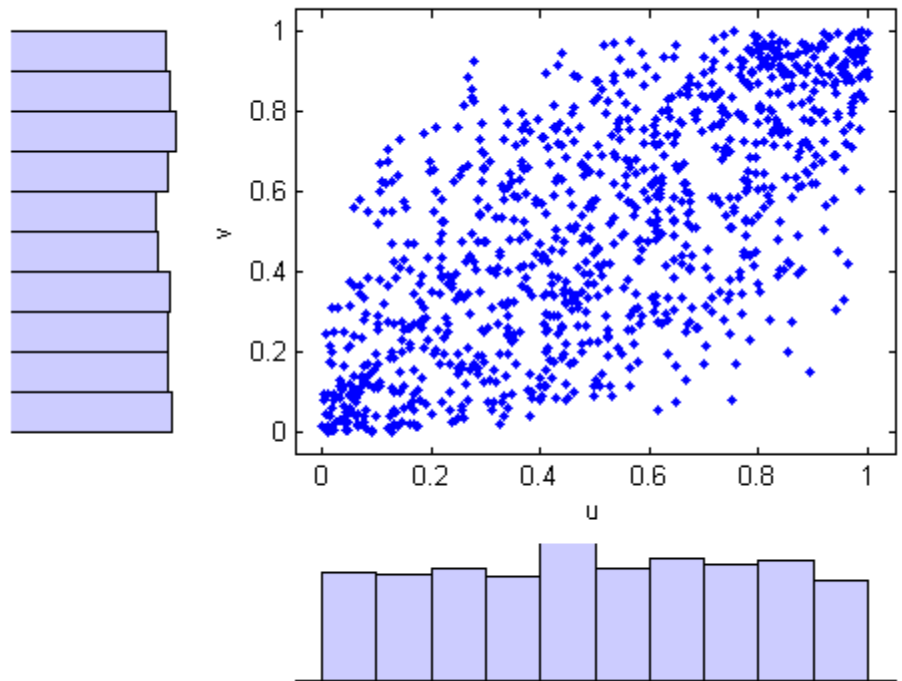
```
r = copularnd('t',Rho,nu,1000);
```

```

u1 = r(:,1);
v1 = r(:,2);

scatterhist(u1,v1)
xlabel('u')
ylabel('v')
set(get(gca,'children'),'marker','.')

```



Transform the random sample back to the original scale of the data:

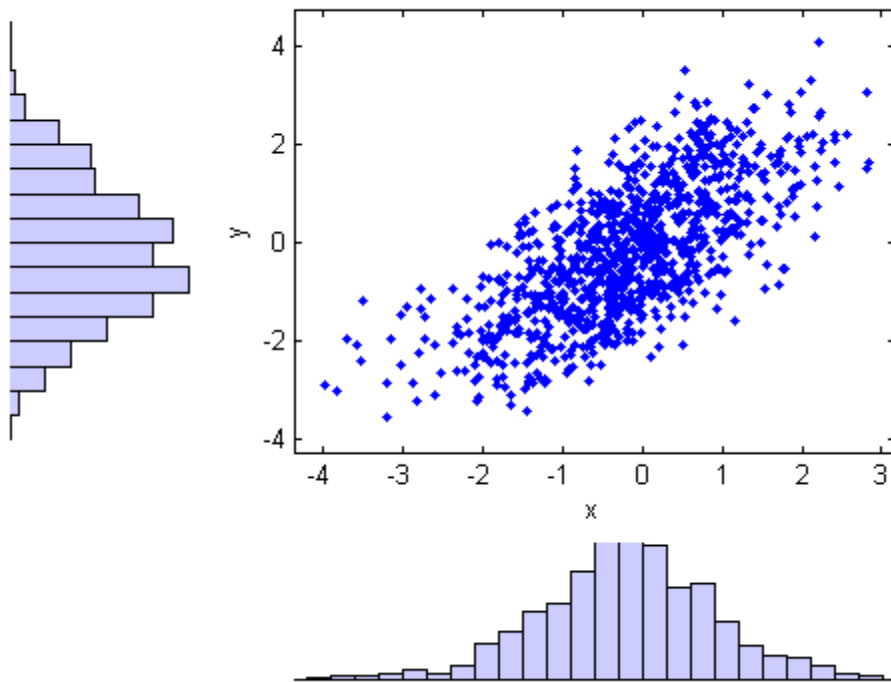
```

x1 = ksdensity(x,u1,'function','icdf');

```

copulafit

```
y1 = ksdensity(y,v1,'function','icdf');  
  
scatterhist(x1,y1)  
set(get(gca,'children'),'marker','.')
```



See Also

[ecdf](#) | [copulacdf](#) | [copulaparam](#) | [copulapdf](#) | [copularnd](#) | [copulastat](#)

Purpose

Copula parameters as function of rank correlation

Syntax

```
rho = copulaparam('Gaussian',R)
rho = copulaparam('t',R,NU)
alpha = copulaparam(family,R)
[...] = copulaparam(...,'type',type)
```

Description

`rho = copulaparam('Gaussian',R)` returns the linear correlation parameters `rho` corresponding to a Gaussian copula having Kendall's rank correlation `R`. If `R` is a scalar correlation coefficient, `rho` is a scalar correlation coefficient corresponding to a bivariate copula. If `R` is a p -by- p correlation matrix, `rho` is a p -by- p correlation matrix.

`rho = copulaparam('t',R,NU)` returns the linear correlation parameters `rho` corresponding to a `t` copula having Kendall's rank correlation `R` and degrees of freedom `NU`. If `R` is a scalar correlation coefficient, `rho` is a scalar correlation coefficient corresponding to a bivariate copula. If `R` is a p -by- p correlation matrix, `rho` is a p -by- p correlation matrix.

`alpha = copulaparam(family,R)` returns the copula parameter `alpha` corresponding to a bivariate Archimedean copula having Kendall's rank correlation `R`. `R` is a scalar. `family` is one of 'Clayton', 'Frank', or 'Gumbel'.

`[...] = copulaparam(...,'type',type)` assumes `R` is the specified type of rank correlation. `type` is 'Kendall' for Kendall's tau or 'Spearman' for Spearman's rho.

`copulaparam` uses an approximation to Spearman's rank correlation for copula families when no analytic formula exists. The approximation is based on a smooth fit to values computed at discrete values of the copula parameters. For a `t` copula, the approximation is accurate for degrees of freedom larger than 0.05.

Examples

Get the linear correlation coefficient corresponding to a bivariate Gaussian copula having a rank correlation of -0.5.

```
tau = -0.5
```

copulaparam

```
rho = copulaparam('gaussian',tau)
rho =
    -0.7071

% Generate dependent beta random values using that copula
u = copularnd('gaussian',rho,100);
b = betainv(u,2,2);

% Verify that the sample has a rank correlation
% approximately equal to tau
tau_sample = corr(b,'type','k')
tau_sample =
    1.0000    -0.4638
   -0.4638    1.0000
```

See Also

[copulacdf](#) | [copulapdf](#) | [copularnd](#) | [copulastat](#)

Purpose

Copula probability density function

Syntax

```
Y = copulapdf('Gaussian',U,rho)
Y = copulapdf('t',U,rho,NU)
Y = copulapdf('family',U,alpha)
```

Description

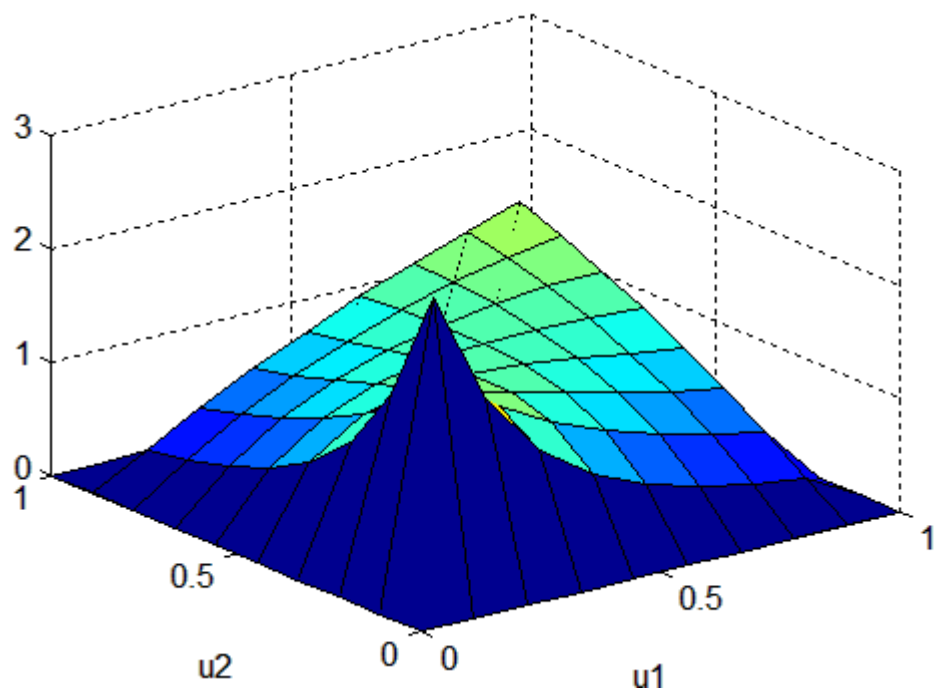
`Y = copulapdf('Gaussian',U,rho)` returns the probability density of the Gaussian copula with linear correlation parameters `rho`, evaluated at the points in `U`. `U` is an `n`-by-`p` matrix of values in `[0,1]`, representing `n` points in the `p`-dimensional unit hypercube. `rho` is a `p`-by-`p` correlation matrix. If `U` is an `n`-by-2 matrix, `rho` may also be a scalar correlation coefficient.

`Y = copulapdf('t',U,rho,NU)` returns the probability density of the `t` copula with linear correlation parameters `rho` and degrees of freedom parameter `NU`, evaluated at the points in `U`. `U` is an `n`-by-`p` matrix of values in `[0,1]`. `rho` is a `p`-by-`p` correlation matrix. If `U` is an `n`-by-2 matrix, `rho` may also be a scalar correlation coefficient.

`Y = copulapdf('family',U,alpha)` returns the probability density of the bivariate Archimedean copula determined by `family`, with scalar parameter `alpha`, evaluated at the points in `U`. `family` is Clayton, Frank, or Gumbel. `U` is an `n`-by-2 matrix of values in `[0,1]`.

Examples

```
u = linspace(0,1,10);
[U1,U2] = meshgrid(u,u);
F = copulapdf('Clayton',[U1(:) U2(:)],1);
surf(U1,U2,reshape(F,10,10))
xlabel('u1')
ylabel('u2')
```



See Also

[copulacdf](#) | [copulaparam](#) | [copularnd](#) | [copulastat](#)

Purpose

Copula rank correlation

Syntax

```
R = copulastat('Gaussian',rho)
R = copulastat('t',rho,NU)
R = copulastat(family,alpha)
R = copulastat(...,'type',type)
```

Description

`R = copulastat('Gaussian',rho)` returns the Kendall's rank correlation R that corresponds to a Gaussian copula having linear correlation parameters ρ . If ρ is a scalar correlation coefficient, R is a scalar correlation coefficient corresponding to a bivariate copula. If ρ is a p -by- p correlation matrix, R is a p -by- p correlation matrix.

`R = copulastat('t',rho,NU)` returns the Kendall's rank correlation R that corresponds to a t copula having linear correlation parameters ρ and degrees of freedom NU . If ρ is a scalar correlation coefficient, R is a scalar correlation coefficient corresponding to a bivariate copula. If ρ is a p -by- p correlation matrix, R is a p -by- p correlation matrix.

`R = copulastat(family,alpha)` returns the Kendall's rank correlation R that corresponds to a bivariate Archimedean copula with scalar parameter α . `family` is one of 'Clayton', 'Frank', or 'Gumbel'.

`R = copulastat(...,'type',type)` returns the specified type of rank correlation. `type` is 'Kendall' to compute Kendall's tau, or 'Spearman' to compute Spearman's rho.

`copulastat` uses an approximation to Spearman's rank correlation for copula families when no analytic formula exists. The approximation is based on a smooth fit to values computed at discrete values of the copula parameters. For a t copula, the approximation is accurate for degrees of freedom larger than 0.05.

Examples

Get the theoretical rank correlation coefficient for a bivariate.

```
% Gaussian copula with linear correlation parameter rho
rho = -.7071;
tau = copulastat('gaussian',rho)
tau =
```

```
-0.5000
```

```
% Generate dependent beta random values using that copula  
u = copularnd('gaussian',rho,100);  
b = betainv(u,2,2);
```

```
% Verify that the sample has a rank correlation  
% approximately equal to tau  
tau_sample = corr(b,'type','k')  
tau_sample =  
    1.0000   -0.5265  
   -0.5265    1.0000
```

See Also

[copulacdf](#) | [copulaparam](#) | [copulapdf](#) | [copularnd](#)

Purpose	Copula random numbers
Syntax	<pre>U = copularnd('Gaussian',rho,N) U = copularnd('t',rho,NU,N) U = copularnd('family',alpha,N)</pre>
Description	<p><code>U = copularnd('Gaussian',rho,N)</code> returns N random vectors generated from a Gaussian copula with linear correlation parameters <code>rho</code>. If <code>rho</code> is a p-by-p correlation matrix, <code>U</code> is an n-by-p matrix. If <code>rho</code> is a scalar correlation coefficient, <code>copularnd</code> generates <code>U</code> from a bivariate Gaussian copula. Each column of <code>U</code> is a sample from a <code>Uniform(0,1)</code> marginal distribution.</p> <p><code>U = copularnd('t',rho,NU,N)</code> returns N random vectors generated from a <code>t</code> copula with linear correlation parameters <code>rho</code> and degrees of freedom <code>NU</code>. If <code>rho</code> is a p-by-p correlation matrix, <code>U</code> is an n-by-p matrix. If <code>rho</code> is a scalar correlation coefficient, <code>copularnd</code> generates <code>U</code> from a bivariate <code>t</code> copula. Each column of <code>U</code> is a sample from a <code>Uniform(0,1)</code> marginal distribution.</p> <p><code>U = copularnd('family',alpha,N)</code> returns N random vectors generated from the bivariate Archimedean copula determined by <code>family</code>, with scalar parameter <code>alpha</code>. <code>family</code> is Clayton, Frank, or Gumbel. <code>U</code> is an n-by-2 matrix. Each column of <code>U</code> is a sample from a <code>Uniform(0,1)</code> marginal distribution.</p>
Examples	<p>Determine the linear correlation parameter corresponding to a bivariate Gaussian copula having a rank correlation of <code>-0.5</code>.</p> <pre>tau = -0.5 rho = copulaparam('gaussian',tau) rho = -0.7071</pre> <p><code>% Generate dependent beta random values using that copula</code></p> <pre>u = copularnd('gaussian',rho,100); b = betainv(u,2,2);</pre>

copularnd

```
% Verify that the sample has a rank correlation
% approximately equal to tau
tau_sample = corr(b,'type','kendall')
tau_sample =
    1.0000   -0.4537
   -0.4537    1.0000
```

See Also

[copulacdf](#) | [copulaparam](#) | [copulapdf](#) | [copulastat](#)

Purpose

Coordinate exchange

Syntax

```
dCE = cordexch(nfactors,nruns)
[dCE,X] = cordexch(nfactors,nruns)
[dCE,X] = cordexch(nfactors,nruns,'model')
[dCE,X] = cordexch(...,'name',value)
```

Description

`dCE = cordexch(nfactors,nruns)` uses a coordinate-exchange algorithm to generate a D -optimal design `dCE` with `nruns` runs (the rows of `dCE`) for a linear additive model with `nfactors` factors (the columns of `dCE`). The model includes a constant term.

`[dCE,X] = cordexch(nfactors,nruns)` also returns the associated design matrix `X`, whose columns are the model terms evaluated at each treatment (row) of `dCE`.

`[dCE,X] = cordexch(nfactors,nruns,'model')` uses the linear regression model specified in `model`. `model` is one of the following strings, specified inside single quotes:

- `linear` — Constant and linear terms. This is the default.
- `interaction` — Constant, linear, and interaction terms
- `quadratic` — Constant, linear, interaction, and squared terms
- `purequadratic` — Constant, linear, and squared terms

The order of the columns of `X` for a full quadratic model with n terms is:

- 1** The constant term
- 2** The linear terms in order 1, 2, ..., n
- 3** The interaction terms in order (1, 2), (1, 3), ..., (1, n), (2, 3), ..., ($n-1$, n)
- 4** The squared terms in order 1, 2, ..., n

Other models use a subset of these terms, in the same order.

Alternatively, *model* can be a matrix specifying polynomial terms of arbitrary order. In this case, *model* should have one column for each factor and one row for each term in the model. The entries in any row of *model* are powers for the factors in the columns. For example, if a model has factors *X1*, *X2*, and *X3*, then a row [0 1 2] in *model* specifies the term $(X1.^0) \cdot (X2.^1) \cdot (X3.^2)$. A row of all zeros in *model* specifies a constant term, which can be omitted.

[dCE,X] = cordexch(..., 'name', value) specifies one or more optional name/value pairs for the design. Valid parameters and their values are listed in the following table. Specify *name* inside single quotes.

name	Value
bounds	Lower and upper bounds for each factor, specified as a 2-by-nfactors matrix. Alternatively, this value can be a cell array containing nfactors elements, each element specifying the vector of allowable values for the corresponding factor.
categorical	Indices of categorical predictors.
display	Either 'on' or 'off' to control display of the iteration counter. The default is 'on'.
excludefun	Handle to a function that excludes undesirable runs. If the function is <i>f</i> , it must support the syntax $b = f(S)$, where <i>S</i> is a matrix of treatments with nfactors columns and <i>b</i> is a vector of Boolean values with the same number of rows as <i>S</i> . <i>b</i> (<i>i</i>) is true if the method should exclude <i>i</i> th row <i>S</i> .
init	Initial design as a nruns-by-nfactors matrix. The default is a randomly selected set of points.
levels	Vector of number of levels for each factor. Not used when bounds is specified as a cell array
maxiter	Maximum number of iterations. The default is 10.

name	Value
tries	Number of times to try to generate a design from a new starting point. The algorithm uses random points for each try, except possibly the first. The default is 1.
options	<p>A structure that specifies whether to run in parallel, and specifies the random stream or streams. Create the options structure with <code>statset</code>. Option fields:</p> <ul style="list-style-type: none"> • <code>UseParallel</code> — Set to 'always' to compute in parallel. Default is 'never'. • <code>UseSubstreams</code> — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set <code>Streams</code> to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'. • <code>Streams</code> — A <code>RandStream</code> object or cell array of such objects. If you do not specify <code>Streams</code>, <code>cordexch</code> uses the default stream or streams. If you choose to specify <code>Streams</code>, use a single object except in the case <ul style="list-style-type: none"> ▪ You have an open MATLAB pool ▪ <code>UseParallel</code> is 'always' ▪ <code>UseSubstreams</code> is 'never' <p>In that case, use a cell array the same size as the MATLAB pool.</p>

Algorithms

Both `cordexch` and `rowexch` use iterative search algorithms. They operate by incrementally changing an initial design matrix X to increase $D = |X^T X|$ at each step. In both algorithms, there is randomness built into the selection of the initial design and into the choice of the incremental changes. As a result, both algorithms may return locally, but not globally, D -optimal designs. Run each algorithm multiple times

and select the best result for your final design. Both functions have a 'tries' parameter that automates this repetition and comparison.

Unlike the row-exchange algorithm used by rowexch, cordexch does not use a candidate set. (Or rather, the candidate set is the entire design space.) At each step, the coordinate-exchange algorithm exchanges a single element of X with a new element evaluated at a neighboring point in design space. The absence of a candidate set reduces demands on memory, but the smaller scale of the search means that the coordinate-exchange algorithm is more likely to become trapped in a local minimum.

Examples

Suppose you want a design to estimate the parameters in the following three-factor, seven-term interaction model:

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 + \varepsilon$$

Use cordexch to generate a D -optimal design with seven runs:

```
nfactors = 3;
nruns = 7;
[dCE,X] = cordexch(nfactors,nruns,'interaction','tries',10)
dCE =
    -1     1     1
    -1    -1    -1
     1     1     1
    -1     1    -1
     1    -1     1
     1    -1    -1
    -1    -1     1
X =
     1    -1     1     1    -1    -1     1
     1    -1    -1    -1     1     1     1
     1     1     1     1     1     1     1
     1    -1     1    -1    -1     1    -1
     1     1    -1     1    -1     1    -1
     1     1    -1    -1    -1    -1     1
     1    -1    -1     1     1    -1    -1
```

Columns of the design matrix X are the model terms evaluated at each row of the design dCE . The terms appear in order from left to right: constant term, linear terms (1, 2, 3), interaction terms (12, 13, 23). Use X to fit the model, as described in “Linear Regression” on page 9-7, to response data measured at the design points in dCE .

See Also

rowexch | daugment | dcovary

Purpose Linear or rank correlation

Syntax

```
RHO = corr(X)
RHO = corr(X,Y)
[RHO,PVAL] = corr(X,Y)
[RHO,PVAL] = corr(X,Y, 'name', value)
```

Description

`RHO = corr(X)` returns a p -by- p matrix containing the pairwise linear correlation coefficient between each pair of columns in the n -by- p matrix X .

`RHO = corr(X,Y)` returns a $p1$ -by- $p2$ matrix containing the pairwise correlation coefficient between each pair of columns in the n -by- $p1$ and n -by- $p2$ matrices X and Y .

The difference between `corr(X,Y)` and the MATLAB function `corrcoef(X,Y)` is that `corrcoef(X,Y)` returns a matrix of correlation coefficients for the two column vectors X and Y . If X and Y are not column vectors, `corrcoef(X,Y)` converts them to column vectors.

`[RHO,PVAL] = corr(X,Y)` also returns `PVAL`, a matrix of p -values for testing the hypothesis of no correlation against the alternative that there is a nonzero correlation. Each element of `PVAL` is the p value for the corresponding element of `RHO`. If `PVAL(i,j)` is small, say less than 0.05, then the correlation `RHO(i,j)` is significantly different from zero.

`[RHO,PVAL] = corr(X,Y, 'name', value)` specifies one or more optional name/value pairs. Specify *name* inside single quotes. The following table lists valid parameters and their values.

Parameter	Values
type	<ul style="list-style-type: none"> 'Pearson' (the default) computes Pearson's linear correlation coefficient 'Kendall' computes Kendall's tau 'Spearman' computes Spearman's rho
rows	<ul style="list-style-type: none"> 'all' (the default) uses all rows regardless of missing values (NaNs) 'complete' uses only rows with no missing values 'pairwise' computes $RHO(i, j)$ using rows with no missing values in column i or j
tail — The alternative hypothesis against which to compute p -values for testing the hypothesis of no correlation	<ul style="list-style-type: none"> 'both' — Correlation is not zero (the default) 'right' — Correlation is greater than zero 'left' — Correlation is less than zero

Using the 'pairwise' option for the rows parameter may return a matrix that is not positive definite. The 'complete' option always returns a positive definite matrix, but in general the estimates are based on fewer observations.

corr computes p -values for Pearson's correlation using a Student's t distribution for a transformation of the correlation. This correlation is exact when X and Y are normal. corr computes p -values for Kendall's tau and Spearman's rho using either the exact permutation distributions (for small sample sizes), or large-sample approximations.

corr computes p -values for the two-tailed test by doubling the more significant of the two one-tailed p -values.

Example

Find the correlation between two matrices and compare to the correlation between two column vectors.

Generate sample data.

```
rng('default')
x = randn(30,4);
y = randn(30,4);
y(:,4) = sum(x,2); % introduce correlation
```

Calculate the correlation between columns of X and Y.

```
[r,p] = corr(x,y)
```

r =

```
-0.1686   -0.0363    0.2278    0.6901
 0.3022    0.0332   -0.0866    0.2617
-0.3632   -0.0987   -0.0200    0.3504
-0.1365   -0.1804    0.0853    0.4908
```

p =

```
0.3731    0.8489    0.2260    0.0000
0.1045    0.8619    0.6491    0.1624
0.0485    0.6039    0.9166    0.0577
0.4721    0.3400    0.6539    0.0059
```

Calculate the correlation between X and Y using corrcoef.

```
[r,p] = corrcoef(x,y)
```

r =

```
1.0000    0.1252
0.1252    1.0000
```

p =

```
1.0000    0.1729
0.1729    1.0000
```

MATLAB function `corrcoef` converts X and Y into column vectors before computing the correlation between them.

References

- [1] Gibbons, J.D. (1985) Nonparametric Statistical Inference, 2nd ed., M. Dekker.
- [2] Hollander, M. and D.A. Wolfe (1973) Nonparametric Statistical Methods, Wiley.
- [3] Kendall, M.G. (1970) Rank Correlation Methods, Griffin.
- [4] Best, D.J. and D.E. Roberts (1975) "Algorithm AS 89: The Upper Tail Probabilities of Spearman's rho", Applied Statistics, 24:377-379.

See Also

`corrcoef` | `partialcorr` | `corrcoef` | `tiedrank`

corrcoef

Purpose Convert covariance matrix to correlation matrix

Syntax `R = corrcoef(C)`
`[R,sigma] = corrcoef(C)`

Description `R = corrcoef(C)` computes the correlation matrix `R` corresponding to the covariance matrix `C`. `C` must be square, symmetric, and positive semi-definite.

`[R,sigma] = corrcoef(C)` also computes the vector of standard deviations `sigma`.

Examples Use `cov` and `corrcoef` to compute covariances and correlations, respectively, for sample data on weight and blood pressure (systolic, diastolic) in `hospital.mat`:

```
load hospital
X = [hospital.Weight hospital.BloodPressure];
C = cov(X)
C =
    706.0404    27.7879    41.0202
    27.7879    45.0622    23.8194
    41.0202    23.8194    48.0590
R = corrcoef(X)
R =
    1.0000    0.1558    0.2227
    0.1558    1.0000    0.5118
    0.2227    0.5118    1.0000
```

Compare `R` with the correlation matrix computed from `C` by `corrcoef`:

```
corrcoef(C)
ans =
    1.0000    0.1558    0.2227
    0.1558    1.0000    0.5118
    0.2227    0.5118    1.0000
```

See Also `cov` | `corrcoef` | `corr` | `cholcov`

Purpose	Misclassification costs
Description	The Cost property is a matrix with misclassification costs. This property is empty for ensembles of regression trees.
See Also	<code>classregtree</code>

gmdistribution.CovType property

Purpose Type of covariance matrices

Description The string 'diagonal' if the covariance matrices are restricted to be diagonal; the string 'full' otherwise.

Purpose Cox proportional hazards regression

Syntax

```
b = coxphfit(X,y)
b = coxphfit(X,y,'name',value)
[b,logl,H,stats] = coxphfit(...)
```

Description `b = coxphfit(X,y)` returns a p -by-1 vector `b` of coefficient estimates for a Cox proportional hazards regression of the responses in `y` on the predictors in `X`. `X` is an n -by- p matrix of p predictors at each of n observations. `y` is an n -by-1 vector of observed responses.

The phrase $h(t) \cdot \exp(X \cdot b)$ models the hazard rate for the distribution of `y`, where $h(t)$ is a common baseline hazard function. The model does not include a constant term, and `X` cannot contain a column of 1s.

`b = coxphfit(X,y,'name',value)` specifies one or more optional parameter name/value pairs chosen from the following table. Specify `name` inside single quotes.

Name	Value
baseline	The <code>X</code> values at which to compute the baseline hazard. Default is <code>mean(X)</code> , so the hazard at <code>X</code> is $h(t) \cdot \exp((X - \text{mean}(X)) \cdot b)$. Enter 0 to compute the baseline relative to 0, so the hazard at <code>X</code> is $h(t) \cdot \exp(X \cdot b)$.
censoring	A Boolean array of the same size as <code>y</code> that is 1 for observations that are right-censored and 0 for observations that are observed exactly. Default is all observations observed exactly.
frequency	An array of the same size as <code>y</code> containing nonnegative integer counts. The j^{th} element of this vector gives the number of times the method observes the j^{th} element of <code>y</code> and the j^{th} row of <code>X</code> . Default is one observation per row of <code>X</code> and <code>y</code> .

Name	Value
init	A vector containing initial values for the estimated coefficients <code>b</code> .
options	A structure specifying control parameters for the iterative algorithm used to estimate <code>b</code> . A call to <code>statset</code> can create this argument. For parameter names and default values, type <code>statset('coxphfit')</code> .

`[b,logl,H,stats] = coxphfit(...)` returns additional results. `logl` is the log likelihood. `H` is a two-column matrix containing `y` values in the first column and the estimated baseline cumulative hazard evaluated at those values in the second column. `stats` is a structure that contains the fields:

- `beta` — Coefficient estimates (same as `b`)
- `se` — Standard errors of coefficient estimates `b`
- `z` — z statistics for `b` (`b` divided by standard error)
- `p` — p -values for `b`
- `covb` — Estimated covariance matrix for `b`

Examples

Generate Weibull data depending on predictor `x`:

```
x = 4*rand(100,1);  
A = 50*exp(-0.5*x); B = 2;  
y = wblrnd(A,B);
```

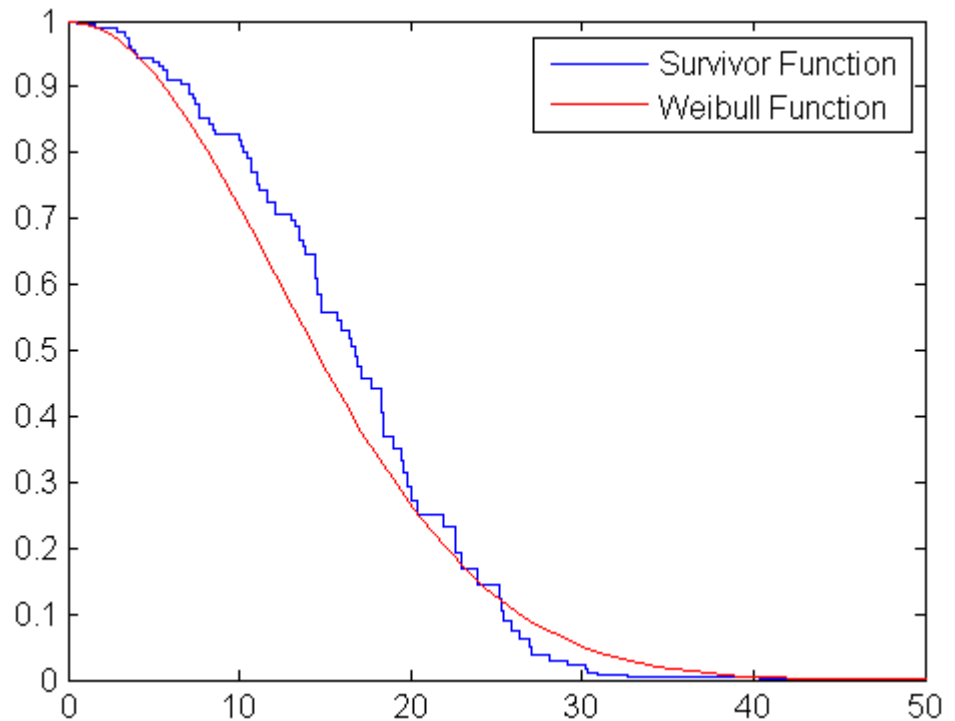
Fit a Cox model :

```
[b,logL,H,stats] = coxphfit(x,y);
```

Show the Cox estimate of the baseline survivor function together with the known Weibull function:

```
stairs(H(:,1),exp(-H(:,2)))
```

```
xx = linspace(0,100);  
line(xx,1-wblcdf(xx,50*exp(-0.5*mean(x)),B),'color','r')  
xlim([0,50])  
legend('Survivor Function','Weibull Function')
```



References

[1] Cox, D.R., and D. Oakes. *Analysis of Survival Data*. London: Chapman & Hall, 1984.

[2] Lawless, J. F. *Statistical Models and Methods for Lifetime Data*. Hoboken, NJ: Wiley-Interscience, 2002.

See Also

ecdf | statset | wblfit

NaiveBayes.CPrior property

Purpose Class priors

Description The CPrior property is a vector of length NClasses containing the class priors. The priors for empty classes are zero.

Purpose

Create object to use in k -nearest neighbors search

Syntax

```
NS = createns(X)
NS = createns(X, 'Name', Value)
```

Description

NS = createns(X) uses the data observations in an $m \times n$ matrix X to create an object NS. Rows of X correspond to observations and columns correspond to variables. NS is either an ExhaustiveSearcher or a KDTreeSearcher object which you can use to find nearest neighbors in X for desired query points. When NS is an ExhaustiveSearcher object, knnsearch uses the exhaustive search algorithm to find nearest neighbors. When NS is a KDTreeSearcher, createns creates and saves a kd -tree based on X in NS. knnsearch uses the kd -tree to find nearest neighbors. For information on these search methods, see “ k -Nearest Neighbor Search and Radius Search” on page 13-12.

NS = createns(X, 'Name', Value) accepts one or more optional name/value pairs. Specify *Name* inside single quotes. Specify NSMethod to determine which type of object to create. The object's properties save the information when you specify other arguments. For more information on the objects' properties, see ExhaustiveSearcher and KDTreeSearcher.

Input Arguments**Name-Value Pair Arguments****NSMethod**

Nearest neighbors search method, used to define the type of object created. Value is either:

- 'kdtree' — Create a KDTreeSearcher object. If you do not specify NSMethod, this is the default value when the number of columns of X is less than 10, X is not sparse, and the distance measure is one of the following measures:
 - 'euclidean' (default)
 - 'cityblock'

- 'minkowski'
- 'chebychev'
- 'exhaustive' — Create an ExhaustiveSearcher object. If you do not specify NSMethod, this is the default value when the default criteria for 'kdtree' do not apply.

Distance

A string or a function handle specifying the default distance metric used when you call the `knnsearch` method to find nearest neighbors for future query points. If you specify a distance metric but not an NSMethod, this input determines the type of object `createns` creates, according to the default values described in NSMethod.

For both `KDTreeSearcher` and `ExhaustiveSearcher` objects, the following options apply:

- 'euclidean' (default) — Euclidean distance.
- 'cityblock' — City block distance.
- 'chebychev' — Chebychev distance (maximum coordinate difference).
- 'minkowski' — Minkowski distance.

The following options apply only to `ExhaustiveSearcher` objects:

- 'seuclidean' — Standardized Euclidean distance. Each coordinate difference between rows in X and the query matrix is scaled by dividing by the corresponding element of the standard deviation computed from X , $S = \text{nanstd}(X)$. To specify another value for S , use the `Scale` argument.
- 'mahalanobis' — Mahalanobis distance, which is computed using a positive definite covariance matrix C . The default value of C is the sample covariance matrix of X , as computed by `nancov(X)`. To change the value of C , use the `Cov` parameter.
- 'cosine' — One minus the cosine of the included angle between observations (treated as vectors).

- 'correlation' — One minus the sample linear correlation between observations (treated as sequences of values).
- 'spearman' — One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
- 'hamming' — Hamming distance, which is percentage of coordinates that differ.
- 'jaccard' — One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ.
- custom distance function — A distance function specified using @ (for example, @distfun). A distance function must be of the form function D2 = distfun(ZI, ZJ), taking as arguments a 1-by- n vector ZI containing a single row from X or from the query points Y, and an m -by- n matrix ZJ containing multiple rows of X or Y, and returning an m -by-1 vector of distances $d2$, whose j th element is the distance between the observations ZI and ZJ(j , :).

P

A positive scalar, p , indicating the exponent of the Minkowski distance. This parameter is only valid when Distance is 'minkowski'. Default is 2.

Cov

A positive definite matrix indicating the covariance matrix when computing the Mahalanobis distance. This parameter is only valid when Distance is 'mahalanobis'. Default is `nancov(X)`.

Scale

A vector S with the length equal to the number of columns in X. Each coordinate of X and each query point is scaled by the corresponding element of S when computing the standardized Euclidean distance. This parameter is only valid when Distance is 'seuclidean'. Default is `nanstd(X)`.

BucketSize

A positive integer, indicating the maximum number of data points in each leaf node of the *kd*-tree. This argument is only meaningful when using the *kd*-tree search method. Default is 50.

Examples

Create a *kd*-tree with a Minkowski distance metric and a P value of 5:

```
load fisheriris
x = meas(:,3:4);
% Since x has only two columns and the Distance is Minkowski,
% createns creates a KDTreeSearcher object by default:
knnobj = createns(x, 'Distance', 'minkowski', 'P', 5)

knnobj =

KDTreeSearcher

Properties:
    BucketSize: 50
              X: [150x2 double]
              Distance: 'minkowski'
              DistParameter: 5
```

See Also

[ExhaustiveSearcher.knnsearch](#) | [KDTreeSearcher.knnsearch](#) | [ExhaustiveSearcher](#) | [KDTreeSearcher](#)

How To

- “*k*-Nearest Neighbor Search and Radius Search” on page 13-12

Purpose Cross-tabulation

Syntax

```
table = crosstab(x1,x2)
table = crosstab(x1,x2,...,xn)
[table,chi2,p] = crosstab(x1,...,xn)
[table,chi2,p,labels] = crosstab(x1,...,xn)
```

Description `table = crosstab(x1,x2)` returns a cross-tabulation table of two vectors of the same length `x1` and `x2`. `table` is *m*-by-*n*, where *m* is the number of distinct values in `x1` and *n* is the number of distinct values in `x2`.

`x1` and `x2` are grouping variables, as described in “Grouping Variables” on page 2-72. `crosstab` uses `grp2idx` to assign a positive integer to each distinct value. `table(i,j)` is a count of indices where `grp2idx(x1)` is *i* and `grp2idx(x2)` is *j*. The numerical order of `grp2idx(x1)` and `grp2idx(x2)` order rows and columns of `table`, respectively.

`table = crosstab(x1,x2,...,xn)` returns a multi-dimensional table where `table(i,j,...,n)` is a count of indices where `grp2idx(x1)` is *i*, `grp2idx(x2)` is *j*, `grp2idx(x3)` is *k*, and so on.

`[table,chi2,p] = crosstab(x1,...,xn)` also returns the chi-square statistic `chi2` and its *p* value `p` for a test that `table` is independent in each dimension. The null hypothesis is that the proportion in any entry of `table` is the product of the proportions in each dimension.

`[table,chi2,p,labels] = crosstab(x1,...,xn)` also returns a cell array `labels` with one column for each input argument. The entries in the first column are labels for the rows of `table`, the entries in the second column are labels for the columns, and so on, for a multi-dimensional table.

Examples **Example 1**

Cross-tabulate two vectors with three and four distinct values, respectively:

```
x = [1 1 2 3 1]; y = [1 2 5 3 1];
```

```
table = crosstab(x,y)
table =
     2     1     0     0
     0     0     0     1
     0     0     1     0
```

Example 2

Generate two independent vectors, each containing 50 discrete uniform random numbers in the range 1:3:

```
x1 = unidrnd(3,50,1);
x2 = unidrnd(3,50,1);
[table,chi2,p] = crosstab(x1,x2)
table =
     1     6     7
     5     5     2
    11     7     6
chi2 =
    7.5449
p =
    0.1097
```

At the 95% confidence level, the p value fails to reject the null hypothesis that `table` is independent in each dimension.

Example 3

The file `carbig.mat` contains measurements of large model cars during the years 1970-1982:

```
load carbig
[table,chi2,p,labels] = crosstab(cyl4,when,org)
table(:,:,1) =
     82     75     25
     12     22     38
table(:,:,2) =
     0     4     3
     23     26     17
table(:,:,3) =
```

```
      3    3    4
     12   25   32

chi2 =
  207.7689

p =
  0

label =
  'Other'   'Early'   'USA'
  'Four'    'Mid'      'Europe'
  []        'Late'    'Japan'
```

`table` and `label` together show that the number of four-cylinder cars made in the USA during the late period of the data was `table(2,3,1)` or 38 cars.

See Also

`grp2idx` | `tabulate`

How To

- “Grouping Variables” on page 2-72

crossval

Purpose Loss estimate using cross validation

Syntax

```
vals = crossval(fun,X)
vals = crossval(fun,X,Y,...)
mse = crossval('mse',X,y,'Predfun',predfun)
mcr = crossval('mcr',X,y,'Predfun',predfun)
val = crossval(criterion,X1,X2,...,y,'Predfun',predfun)
vals = crossval(...,'name',value)
```

Description `vals = crossval(fun,X)` performs 10-fold cross validation for the function `fun`, applied to the data in `X`.

`fun` is a function handle to a function with two inputs, the training subset of `X`, `XTRAIN`, and the test subset of `X`, `XTEST`, as follows:

```
testval = fun(XTRAIN,XTEST)
```

Each time it is called, `fun` should use `XTRAIN` to fit a model, then return some criterion `testval` computed on `XTEST` using that fitted model.

`X` can be a column vector or a matrix. Rows of `X` correspond to observations; columns correspond to variables or features. Each row of `vals` contains the result of applying `fun` to one test set. If `testval` is a non-scalar value, `crossval` converts it to a row vector using linear indexing and stored in one row of `vals`.

`vals = crossval(fun,X,Y,...)` is used when data are stored in separate variables `X`, `Y`, All variables (column vectors, matrices, or arrays) must have the same number of rows. `fun` is called with the training subsets of `X`, `Y`, ... , followed by the test subsets of `X`, `Y`, ... , as follows:

```
testvals = fun(XTRAIN,YTRAIN,...,XTEST,YTEST,...)
```

`mse = crossval('mse',X,y,'Predfun',predfun)` returns `mse`, a scalar containing a 10-fold cross validation estimate of mean-squared error for the function `predfun`. `X` can be a column vector, matrix, or array of predictors. `y` is a column vector of response values. `X` and `y` must have the same number of rows.

`predfun` is a function handle called with the training subset of X , the training subset of y , and the test subset of X as follows:

```
yfit = predfun(XTRAIN,ytrain,XTEST)
```

Each time it is called, `predfun` should use `XTRAIN` and `ytrain` to fit a regression model and then return fitted values in a column vector `yfit`. Each row of `yfit` contains the predicted values for the corresponding row of `XTEST`. `crossval` computes the squared errors between `yfit` and the corresponding response test set, and returns the overall mean across all test sets.

`mcr = crossval('mcr',X,y,'Predfun',predfun)` returns `mcr`, a scalar containing a 10-fold cross validation estimate of misclassification rate (the proportion of misclassified samples) for the function `predfun`. The matrix X contains predictor values and the vector y contains class labels. `predfun` should use `XTRAIN` and `YTRAIN` to fit a classification model and return `yfit` as the predicted class labels for `XTEST`. `crossval` computes the number of misclassifications between `yfit` and the corresponding response test set, and returns the overall misclassification rate across all test sets.

`val = crossval(criterion,X1,X2,...,y,'Predfun',predfun)`, where *criterion* is 'mse' or 'mcr', returns a cross validation estimate of mean-squared error (for a regression model) or misclassification rate (for a classification model) with predictor values in $X1$, $X2$, ... and, respectively, response values or class labels in y . $X1$, $X2$, ... and y must have the same number of rows. `predfun` is a function handle called with the training subsets of $X1$, $X2$, ..., the training subset of y , and the test subsets of $X1$, $X2$, ..., as follows:

```
yfit=predfun(X1TRAIN,X2TRAIN,...,ytrain,X1TEST,X2TEST,...)
```

`yfit` should be a column vector containing the fitted values.

`vals = crossval(...,'name',value)` specifies one or more optional parameter name/value pairs from the following table. Specify *name* inside single quotes.

crossval

Name	Value
holdout	A scalar specifying the ratio or the number of observations p for holdout cross validation. When $0 < p < 1$, approximately $p \cdot n$ observations for the test set are randomly selected. When p is an integer, p observations for the test set are randomly selected.
kfold	A scalar specifying the number of folds k for k -fold cross validation.
leaveout	Specifies leave-one-out cross validation. The value must be 1.
mcreps	A positive integer specifying the number of Monte-Carlo repetitions for validation. If the first input of <code>crossval</code> is 'mse' or 'mcr', <code>crossval</code> returns the mean of mean-squared error or misclassification rate across all of the Monte-Carlo repetitions. Otherwise, <code>crossval</code> concatenates the values <code>vals</code> from all of the Monte-Carlo repetitions along the first dimension.
partition	An object <code>c</code> of the <code>cvpartition</code> class, specifying the cross validation type and partition.
stratify	A column vector <code>group</code> specifying groups for stratification. Both training and test sets have roughly the same class proportions as in <code>group</code> . NaNs or empty strings in <code>group</code> are treated as missing values, and the corresponding rows of the data are ignored.
options	A structure that specifies whether to run in parallel, and specifies the random stream or streams. Create the <code>options</code> structure with <code>statset</code> . Option fields:

Name	Value
	<ul style="list-style-type: none"> • <code>UseParallel</code> — Set to 'always' to compute in parallel. Default is 'never'. • <code>UseSubstreams</code> — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set <code>Streams</code> to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'. • <code>Streams</code> — A <code>RandStream</code> object or cell array consisting of one such object. If you do not specify <code>Streams</code>, <code>crossval</code> uses the default stream.

Only one of `kfold`, `holdout`, `leaveout`, or `partition` can be specified, and `partition` cannot be specified with `stratify`. If both `partition` and `mcreps` are specified, the first Monte-Carlo repetition uses the partition information in the `cvpartition` object, and the `repartition` method is called to generate new partitions for each of the remaining repetitions. If no cross validation type is specified, the default is 10-fold cross validation.

Note When using cross validation with classification algorithms, stratification is preferred. Otherwise, some test sets may not include observations from all classes.

Examples

Example 1

Compute mean-squared error for regression using 10-fold cross validation:

```
load('fisheriris');
y = meas(:,1);
X = [ones(size(y,1),1),meas(:,2:4)];
```

```
regf=@(XTRAIN,ytrain,XTEST)(XTEST*regress(ytrain,XTRAIN));  
  
cvMse = crossval('mse',X,y,'predfun',regf)  
cvMse =  
    0.1015
```

Example 2

Compute misclassification rate using stratified 10-fold cross validation:

```
load('fisheriris');  
y = species;  
X = meas;  
cp = cvpartition(y,'k',10); % Stratified cross-validation  
  
classf = @(XTRAIN, ytrain,XTEST)(classify(XTEST,XTRAIN,...  
ytrain));  
  
cvMCR = crossval('mcr',X,y,'predfun',classf,'partition',cp)  
cvMCR =  
    0.0200
```

Example 3

Compute the confusion matrix using stratified 10-fold cross validation:

```
load('fisheriris');  
y = species;  
X = meas;  
order = unique(y); % Order of the group labels  
cp = cvpartition(y,'k',10); % Stratified cross-validation  
  
f = @(xtr,ytr,xte,yte)confusionmat(yte,...  
classify(xte,xtr,ytr),'order',order);  
  
cfMat = crossval(f,X,y,'partition',cp);  
cfMat = reshape(sum(cfMat),3,3)  
cfMat =
```

50	0	0
0	48	2
0	1	49

cfMat is the summation of 10 confusion matrices from 10 test sets.

References

[1] Hastie, T., R. Tibshirani, and J. Friedman. *The Elements of Statistical Learning*. New York: Springer, 2001.

See Also

cvpartition

How To

- “Grouping Variables” on page 2-72

ClassificationDiscriminant.crossval

Purpose Cross-validated discriminant analysis classifier

Syntax
`cvmodel = crossval(obj)`
`cvmodel = crossval(obj,Name,Value)`

Description
`cvmodel = crossval(obj)` creates a partitioned model from `obj`, a fitted discriminant analysis classifier. By default, `crossval` uses 10-fold cross validation on the training data to create `cvmodel`.
`cvmodel = crossval(obj,Name,Value)` creates a partitioned model with additional options specified by one or more `Name,Value` pair arguments.

Tips

- Assess the predictive performance of `obj` on cross-validated data using the “kfold” methods and properties of `cvmodel`, such as `kfoldLoss`.

Input Arguments

obj
Discriminant analysis classifier, produced using `ClassificationDiscriminant.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

cvpartition

Object of class `cvpartition`, created by the `cvpartition` function. `crossval` splits the data into subsets with `cvpartition`.

Use only one of these options at a time: `'cvpartition'`, `'holdout'`, `'kfold'`, or `'leaveout'`.

Default: []

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. Use only one of these options at a time: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

kfold

Number of folds to use in a cross-validated classifier, a positive integer.

Use only one of these options at a time: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

Default: 10

leaveout

Set to 'on' for leave-one-out cross validation.

Use only one of these options at a time: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

Examples

Create a classification model for the Fisher iris data, and then create a cross-validation model. Evaluate the quality the model using `kfoldLoss`.

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
cvmodel = crossval(obj);
L = kfoldLoss(cvmodel)

L =
    0.0200
```

Alternatives

You can create a cross-validation classifier directly from the data, instead of creating a discriminant analysis classifier followed by a cross-validation classifier. To do so, include one of these options in

ClassificationDiscriminant.crossval

ClassificationDiscriminant.fit: 'crossval', 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

See Also

ClassificationDiscriminant.fit | crossval | kfoldEdge | kfoldfun | kfoldLoss | kfoldMargin | kfoldPredict

How To

- “Discriminant Analysis” on page 12-3

Purpose Cross validate ensemble

Syntax
`cvens = crossval(ens)`
`cvens = crossval(ens,Name,Value)`

Description
`cvens = crossval(ens)` creates a cross-validated ensemble from `ens`, a classification ensemble. Default is 10-fold cross validation.
`cvens = crossval(ens,Name,Value)` creates a cross-validated ensemble with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ,NameN,ValueN`.

Input Arguments
ens
A classification ensemble created with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, . . . ,NameN,ValueN`.

cvpartition

A partition of class `cvpartition`. Sets the partition for cross validation.

Use no more than one of the name-value pairs `cvpartition`, `holdout`, `kfold`, or `leaveout`.

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

ClassificationEnsemble.crossval

kfold

Number of folds for cross validation, a numeric positive scalar.

Use no more than one of the name-value pairs 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

leaveout

If 'on', use leave-one-out cross validation.

Use no more than one of the name-value pairs 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

nprint

Printout frequency, a positive integer scalar. Use this parameter to observe the training of cross-validation folds.

Default: 'off', meaning no printout

Output Arguments

cvens

A cross-validated classification ensemble of class ClassificationPartitionedEnsemble.

Alternatives

You can create a cross-validation ensemble directly from the data, instead of creating an ensemble followed by a cross-validation ensemble. To do so, include one of these five options in fitensemble: 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Examples

Create a cross-validated classification model for the Fisher iris data, and assess its quality using the kfoldLoss method.

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
cvens = crossval(ens);
L = kfoldLoss(cvens)
```

```
L =
    0.0467
```


See Also

ClassificationPartitionedEnsemble | cvpartition

ClassificationKNN.crossval

Purpose Cross-validated k -nearest neighbor classifier

Syntax
`cvmodel = crossval mdl`
`cvmodel = crossval mdl, Name, Value`

Description `cvmodel = crossval mdl` creates a partitioned model from `mdl`, a fitted KNN classification model. By default, `crossval` uses 10-fold cross validation on the training data to create `cvmodel`.

`cvmodel = crossval mdl, Name, Value` creates a partitioned model with additional options specified by one or more `Name, Value` pair arguments.

Tips

- Assess the predictive performance of `mdl` on cross-validated data using the “kfold” methods and properties of `cvmodel`, such as `kfoldLoss`.

Input Arguments

mdl

k -nearest neighbor classifier, created by `ClassificationKNN.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

cvpartition

Object of class `cvpartition`, created by the `cvpartition` function. `crossval` splits the data into subsets with `cvpartition`.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

holdout

Holdout validation tests the specified fraction of the data, and uses the remaining data for training. Specify a numeric scalar from 0 to 1. Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Set to 'on' for leave-one-out cross validation.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Output Arguments

cvmodel

Partitioned model of class `ClassificationPartitionedModel`.

Examples

Cross-Validated K-Nearest Neighbor Model

Construct a cross-validated k -nearest neighbor model, and assess classification performance using the model.

Load the data.

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y);
```

Construct a cross-validated classifier.

ClassificationKNN.crossval

```
cvmdl = crossval(md1)

cvmdl =

classreg.learning.partition.ClassificationPartitionedModel:
  CrossValidatedModel: 'KNN'
  PredictorNames: {'x1' 'x2' 'x3' 'x4'}
  CategoricalPredictors: []
  ResponseName: 'Y'
  NObservations: 150
  KFold: 10
  Partition: [1x1 cvpartition]
  ClassNames: {'setosa' 'versicolor' 'virginica'}
  ScoreTransform: 'none'
```

Find the cross-validated loss of the classifier.

```
cvmdlloss = kfoldLoss(cvmdl)

cvmdlloss =

    0.0400
```

The cross-validated loss is less than 5%. You can expect `md1` to have a similar error rate.

Alternatives

You can create a cross-validated model directly from the data, instead of creating a model followed by a cross-validated model. To do so, include one of these options in `ClassificationKNN.fit`: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`.

See Also

`ClassificationKNN` | `ClassificationPartitionedModel` | `crossvalkfoldEdge` | `kfoldfun` | `kfoldLoss` | `kfoldMargin` | `kfoldPredict` |

Related Examples

- “Examine the Quality of a KNN Classifier” on page 13-26
- “Modify a KNN Classifier” on page 13-27

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

ClassificationTree.crossval

Purpose Cross-validated decision tree

Syntax
`cvmodel = crossval(model)`
`cvmodel = crossval(model,Name,Value)`

Description `cvmodel = crossval(model)` creates a partitioned model from `model`, a fitted classification tree. By default, `crossval` uses 10-fold cross validation on the training data to create `cvmodel`.

`cvmodel = crossval(model,Name,Value)` creates a partitioned model with additional options specified by one or more `Name,Value` pair arguments.

Tips

- Assess the predictive performance of `model` on cross-validated data using the “kfold” methods and properties of `cvmodel`, such as `kfoldLoss`.

Input Arguments

model
A classification model, produced using `ClassificationTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

cvpartition

Object of class `cvpartition`, created by the `cvpartition` function. `crossval` splits the data into subsets with `cvpartition`.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

holdout

Holdout validation tests the specified fraction of the data, and uses the remaining data for training. Specify a numeric scalar from 0 to 1. Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Set to 'on' for leave-one-out cross validation.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Output Arguments

cvmodel

Partitioned model of class `ClassificationPartitionedModel`.

Examples

Create a classification model for the ionosphere data, then create a cross-validation model. Evaluate the quality the model using `kfoldLoss`.

```
load ionosphere
tree = ClassificationTree.fit(X,Y);
cvmodel = crossval(tree);
L = kfoldLoss(cvmodel)
```

```
L =
    0.1168
```

Alternatives

You can create a cross-validation tree directly from the data, instead of creating a decision tree followed by a cross-validation tree. To do

ClassificationTree.crossval

so, include one of these five options in `ClassificationTree.fit`:
'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

See Also

`ClassificationTree.fit` | `crossval`

Purpose Cross validate ensemble

Syntax
`cvens = crossval(ens)`
`cvens = crossval(ens,Name,Value)`

Description
`cvens = crossval(ens)` creates a cross-validated ensemble from `ens`, a regression ensemble. Default is 10-fold cross validation.
`cvens = crossval(ens,Name,Value)` creates a cross-validated ensemble with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ,NameN,ValueN`.

Input Arguments

ens
A regression ensemble created with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, . . . ,NameN,ValueN`.

cvpartition

A partition of class `cvpartition`. Sets the partition for cross validation.

Use no more than one of the name-value pairs `cvpartition`, `holdout`, `kfold`, and `leaveout`.

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

RegressionEnsemble.crossval

kfold

Number of folds for cross validation, a numeric positive scalar.

Use no more than one of the name-value pairs 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

leaveout

If 'on', use leave-one-out cross-validation.

Use no more than one of the name-value pairs 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

nprint

Printout frequency, a positive integer scalar. Use this parameter to observe the training of cross-validation folds.

Default: 'off', meaning no printout

Output Arguments

cvens

A cross-validated classification ensemble of class RegressionPartitionedEnsemble.

Alternatives

You can create a cross-validation ensemble directly from the data, instead of creating an ensemble followed by a cross-validation ensemble. To do so, include one of these five options in fitensemble: 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Examples

Create a cross-validated classification model for the carsmall data, and assess its quality using the kfoldLoss method:

```
X = [Acceleration Displacement Horsepower Weight];  
rens = fitensemble(X,MPG,'LSBoost',100,'Tree');  
cvens = crossval(rens);  
L = kfoldLoss(cvens)
```

```
L =  
    21.9868
```

See Also

RegressionPartitionedEnsemble | cvpartition

RegressionTree.crossval

Purpose Cross-validated decision tree

Syntax
`cvmodel = crossval(model)`
`cvmodel = crossval(model,Name,Value)`

Description `cvmodel = crossval(model)` creates a partitioned model from `model`, a fitted regression tree. By default, `crossval` uses 10-fold cross validation on the training data to create `cvmodel`.

`cvmodel = crossval(model,Name,Value)` creates a partitioned model with additional options specified by one or more `Name,Value` pair arguments.

Tips

- Assess the predictive performance of `model` on cross-validated data using the “kfold” methods and properties of `cvmodel`, such as `kfoldLoss`.

Input Arguments

model

A regression model, produced using `RegressionTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

cvpartition

Object of class `cvpartition`, created by the `cvpartition` function. `crossval` splits the data into subsets with `cvpartition`.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: []

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer.

Use only one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Set to 'on' for leave-one-out cross-validation.

Output Arguments

cvmodel

A partitioned model of class RegressionPartitionedModel.

Examples

Create a regression model of the carsmall data, and assess its accuracy with kfoldLoss:

```
load carsmall
X = [Acceleration Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
cvtree = crossval(tree);
L = kfoldLoss(cvtree)
```

```
L =
    25.2432
```

Alternatives

You can create a cross-validation tree directly from the data, instead of creating a decision tree followed by a cross-validation tree. To do so,

RegressionTree.crossval

include one of these five options in `RegressionTree.fit`: 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

See Also

`RegressionTree.fit` | `crossval`

Purpose Transpose categorical matrix

Syntax `B = ctranspose(A)`

Description `B = ctranspose(A)` returns the transpose of the 2-D categorical matrix `A`. Note that `ctranspose` is identical to `transpose` for categorical arrays.

See Also `transpose` | `permute`

classregtree.cutcategories

Purpose Cut categories

Syntax `C = cutcategories(t)`
`C = cutcategories(t,nodes)`

Description `C = cutcategories(t)` returns an n -by-2 cell array `C` of the categories used at branches in the decision tree `t`, where n is the number of nodes. For each branch node i based on a categorical predictor variable x , the left child is chosen if x is among the categories listed in `C{i,1}`, and the right child is chosen if x is among those listed in `C{i,2}`. Both columns of `C` are empty for branch nodes based on continuous predictors and for leaf nodes.

`C = cutcategories(t,nodes)` takes a vector `nodes` of node numbers and returns the categories for the specified nodes.

Examples Create a classification tree for car data:

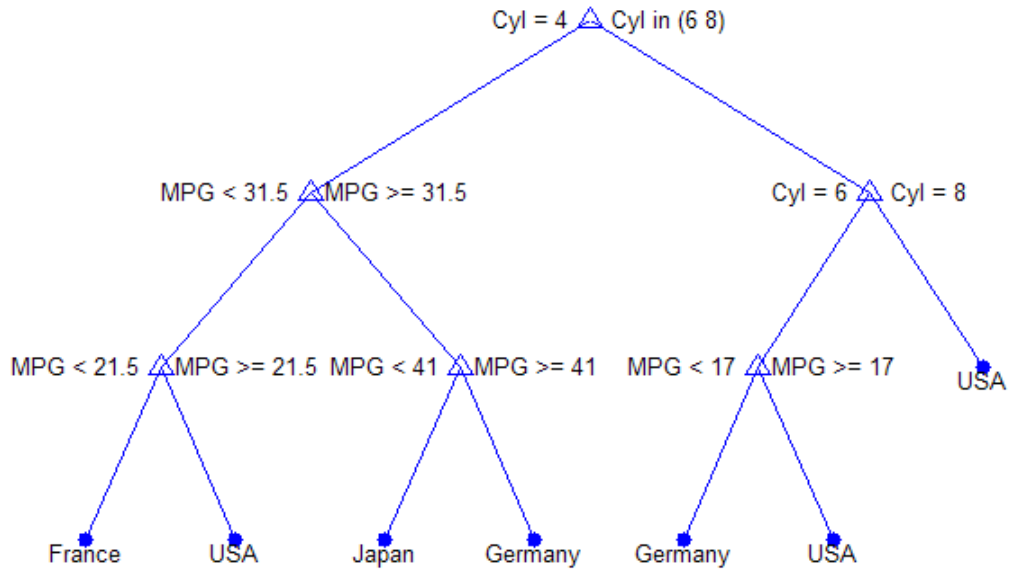
```
load carsmall

t = classregtree([MPG Cylinders],Origin,...
                'names',{'MPG' 'Cyl'},'cat',2)
t =
Decision tree for classification
1  if Cyl=4 then node 2 elseif Cyl in {6 8} then node 3 else USA
2  if MPG<31.5 then node 4 elseif MPG>=31.5 then node 5 else USA
3  if Cyl=6 then node 6 elseif Cyl=8 then node 7 else USA
4  if MPG<21.5 then node 8 elseif MPG>=21.5 then node 9 else USA
5  if MPG<41 then node 10 elseif MPG>=41 then node 11 else Japan
6  if MPG<17 then node 12 elseif MPG>=17 then node 13 else USA
7  class = USA
8  class = France
9  class = USA
10 class = Japan
11 class = Germany
12 class = Germany
13 class = USA
```


classregtree.cutcategories

view(t)

Click to display: Magnification: Pruning level:



```
C = cutcategories(t)
C =
    [4]    [1x2 double]
    []
    [6]    [      8]
    []
    []
    []
    []
    []
    []
```

classregtree.cutcategories

```
      []      []
      []      []
      []      []
      []      []
      []      []
C{1,2}
ans =
     6     8
```

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree | cutpoint | cuttype | cutvar

Purpose Decision tree cut point values

Syntax `v = cutpoint(t)`
`v = cutpoint(t,nodes)`

Description `v = cutpoint(t)` returns an n -element vector v of the values used as cut points in the decision tree t , where n is the number of nodes. For each branch node i based on a continuous predictor variable x , the left child is chosen if $x < v(i)$ and the right child is chosen if $x \geq v(i)$. v is NaN for branch nodes based on categorical predictors and for leaf nodes.

`v = cutpoint(t,nodes)` takes a vector `nodes` of node numbers and returns the cut points for the specified nodes.

Examples Create a classification tree for car data:

```
load carsmall

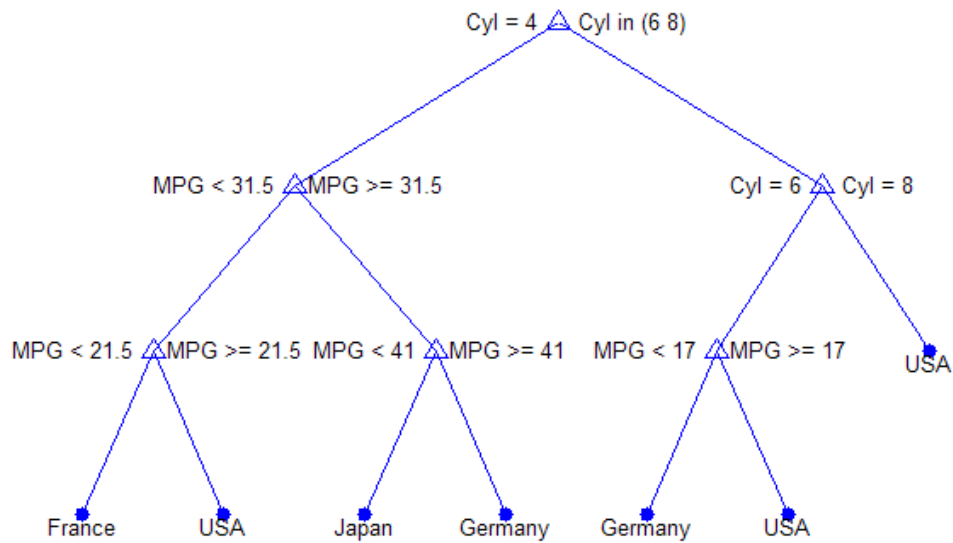
t = classregtree([MPG Cylinders],Origin,...
                'names',{'MPG' 'Cyl'},'cat',2)

t =
Decision tree for classification
 1  if Cyl=4 then node 2 elseif Cyl in {6 8} then node 3 else USA
 2  if MPG<31.5 then node 4 elseif MPG>=31.5 then node 5 else USA
 3  if Cyl=6 then node 6 elseif Cyl=8 then node 7 else USA
 4  if MPG<21.5 then node 8 elseif MPG>=21.5 then node 9 else USA
 5  if MPG<41 then node 10 elseif MPG>=41 then node 11 else Japan
 6  if MPG<17 then node 12 elseif MPG>=17 then node 13 else USA
 7  class = USA
 8  class = France
 9  class = USA
10  class = Japan
11  class = Germany
12  class = Germany
13  class = USA
```

classregtree.cutpoint

view(t)

Click to display: Magnification: Pruning level:



```
v = cutpoint(t)
```

```
v =  
    NaN  
    31.5000  
    NaN  
    21.5000  
    41.0000  
    17.0000  
    NaN  
    NaN  
    NaN  
    NaN
```

NaN
NaN
NaN

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

[classregtree](#) | [cutcategories](#) | [cuttype](#) | [cutvar](#)

classregtree.cuttype

Purpose Cut types

Syntax
`c = cuttype(t)`
`c = cuttype(t,nodes)`

Description `c = cuttype(t)` returns an n -element cell array `c` indicating the type of cut at each node in the tree `t`, where n is the number of nodes. For each node i , `c{i}` is:

- 'continuous' — If the cut is defined in the form $x < v$ for a variable x and cut point v .
- 'categorical' — If the cut is defined by whether a variable x takes a value in a set of categories.
- '' — If i is a leaf node.

`cutvar` returns the cut points for 'continuous' cuts, and `cutcategories` returns the set of categories.

`c = cuttype(t,nodes)` takes a vector `nodes` of node numbers and returns the cut types for the specified nodes.

Examples

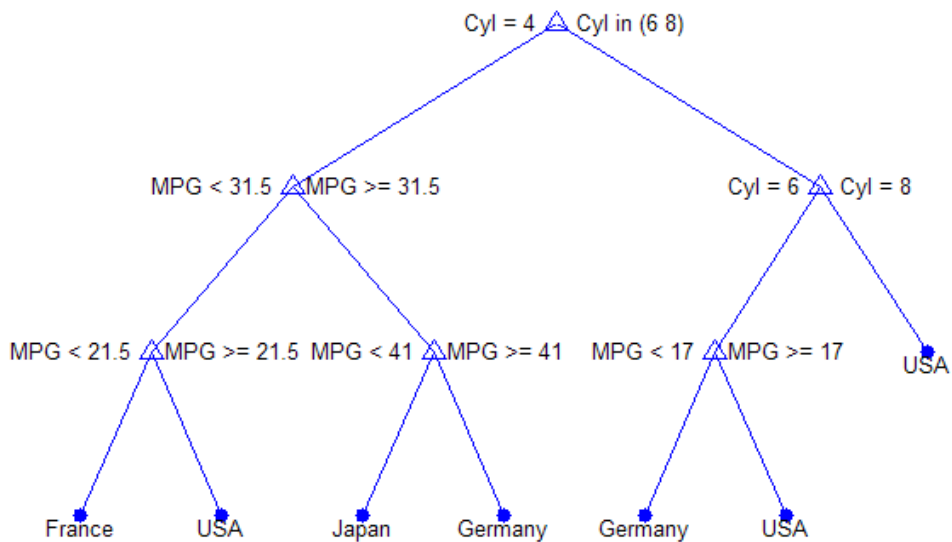
Create a classification tree for car data:

```
load carsmall

t = classregtree([MPG Cylinders],Origin,...
                'names',{'MPG' 'Cyl'},'cat',2)
t =
Decision tree for classification
1  if Cyl=4 then node 2 elseif Cyl in {6 8} then node 3 else USA
2  if MPG<31.5 then node 4 elseif MPG>=31.5 then node 5 else USA
3  if Cyl=6 then node 6 elseif Cyl=8 then node 7 else USA
4  if MPG<21.5 then node 8 elseif MPG>=21.5 then node 9 else USA
5  if MPG<41 then node 10 elseif MPG>=41 then node 11 else Japan
6  if MPG<17 then node 12 elseif MPG>=17 then node 13 else USA
7  class = USA
```

```
8 class = France
9 class = USA
10 class = Japan
11 class = Germany
12 class = Germany
13 class = USA
view(t)
```

Click to display: Magnification: Pruning level:



```
c = cuttype(t)
c =
'categorical'
'continuous'
'categorical'
'continuous'
```

classregtree.cuttype

```
'continuous'  
'continuous'  
''  
''  
''  
''  
''  
''  
''  
''
```

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree | numnodes | cutvar | cutcategories

Purpose

Cut variable names

Syntax

```
v = cutvar(t)
v = cutvar(t,nodes)
[v,num] = cutvar(...)
```

Description

`v = cutvar(t)` returns an n -element cell array `v` of the names of the variables used for branching in each node of the tree `t`, where n is the number of nodes. These variables are sometimes known as *cut variables*. For leaf nodes, `v` contains an empty string.

`v = cutvar(t,nodes)` takes a vector `nodes` of node numbers and returns the cut variables for the specified nodes.

`[v,num] = cutvar(...)` also returns a vector `num` containing the number of each variable.

Examples

Create a classification tree for car data:

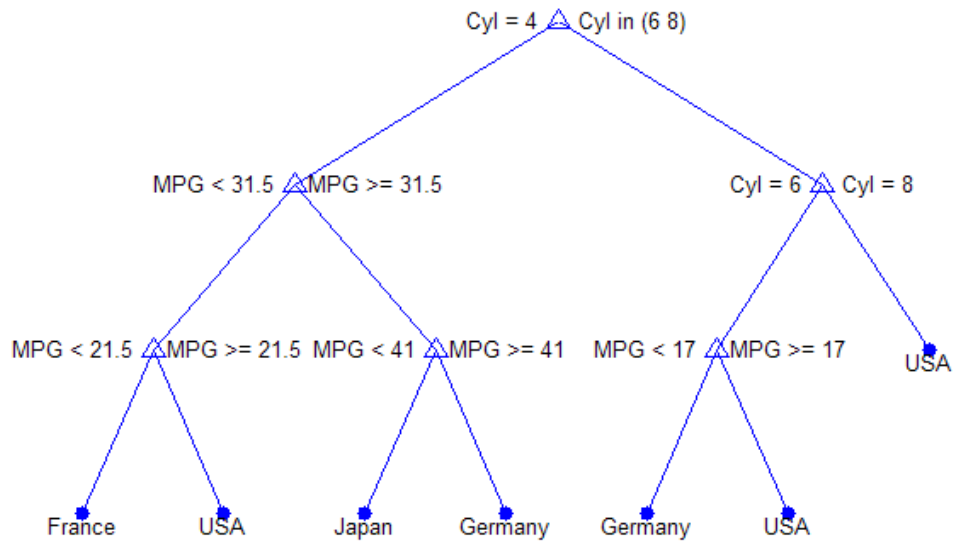
```
load carsmall

t = classregtree([MPG Cylinders],Origin,...
                'names',{'MPG' 'Cyl'},'cat',2)
t =
Decision tree for classification
 1  if Cyl=4 then node 2 elseif Cyl in {6 8} then node 3 else USA
 2  if MPG<31.5 then node 4 elseif MPG>=31.5 then node 5 else USA
 3  if Cyl=6 then node 6 elseif Cyl=8 then node 7 else USA
 4  if MPG<21.5 then node 8 elseif MPG>=21.5 then node 9 else USA
 5  if MPG<41 then node 10 elseif MPG>=41 then node 11 else Japan
 6  if MPG<17 then node 12 elseif MPG>=17 then node 13 else USA
 7  class = USA
 8  class = France
 9  class = USA
10  class = Japan
11  class = Germany
12  class = Germany
13  class = USA
```

classregtree.cutvar

view(t)

Click to display: Magnification: Pruning level:



```
[v,num] = cutvar(t)
```

```
v =
```

```
    'Cyl'
```

```
    'MPG'
```

```
    'Cyl'
```

```
    'MPG'
```

```
    'MPG'
```

```
    'MPG'
```

```
    ''
```

```
    ''
```

```
    ''
```

```
    ''
    ''
    ''
    ''
num =
    2
    1
    2
    1
    1
    1
    0
    0
    0
    0
    0
    0
    0
    0
```

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree | numnodes | children

ClassificationTree.cvLoss

Purpose Classification error by cross validation

Syntax

```
E = cvLoss(tree)
[E,SE] = cvLoss(tree)
[E,SE,Nleaf] = cvLoss(tree)
[E,SE,Nleaf,BestLevel] = cvLoss(tree)
[E,...] = cvLoss(tree,Name,Value)
```

Description

`E = cvLoss(tree)` returns the cross-validated classification error (loss) for `tree`, a classification tree.

`[E,SE] = cvLoss(tree)` returns the standard error of `E`.

`[E,SE,Nleaf] = cvLoss(tree)` returns the number of leaves of `tree`.

`[E,SE,Nleaf,BestLevel] = cvLoss(tree)` returns the optimal pruning level for `tree`.

`[E,...] = cvLoss(tree,Name,Value)` cross validates with additional options specified by one or more `Name, Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

tree

A classification tree produced by `ClassificationTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

subtrees

Vector of pruning levels, with 0 representing the full, unpruned tree. `tree` must include a pruning sequence as created either by `ClassificationTree.fit` with 'prune' set to 'on', or by the

prune method. The returned `E`, `SE`, and `Nleaf` are vectors of the same length as `subtrees`; `BestLevel` is a scalar. If you set `subtrees` to `'all'`, `cvLoss` uses the entire pruning sequence.

Default: 0

treesize

One of the following strings:

- `'se'` — `cvLoss` uses the smallest tree whose cost is within one standard error of the minimum cost.
- `'min'` — `cvLoss` uses the minimal cost tree.

Default: `'se'`

kfold

Number of cross-validation samples, a positive integer.

Default: 10

Output Arguments

E

The cross-validation classification error (loss). A vector or scalar depending on the setting of the `subtrees` name-value pair.

SE

The standard error of `E`. A vector or scalar depending on the setting of the `subtrees` name-value pair.

Nleaf

Number of leaf nodes in `tree`. Leaf nodes are terminal nodes, which give classifications, not splits. A vector or scalar depending on the setting of the `subtrees` name-value pair.

BestLevel

ClassificationTree.cvLoss

By default, a scalar representing the largest pruning level that achieves a value of `E` within `SE` of the minimum error. If you set `treeSize` to `'min'`, `BestLevel` is the smallest value in subtrees.

Examples

Compute the cross-validation error for the default classification tree for the ionosphere data:

```
load ionosphere
tree = ClassificationTree.fit(X,Y);
[E,SE,Nleaf,BestLevel] = cvLoss(tree)
```

```
E =
    0.1282
```

```
SE =
    0.0178
```

```
Nleaf =
    19
```

```
BestLevel =
    0
```

Find the best level by using the subtrees name-value pair:

```
[~,~,~,BestLevel] = cvLoss(tree,'subtrees','all')
```

```
BestLevel =
    6
```

Alternatives

You can construct a cross-validated tree model with `crossval`, and call `kfoldLoss` instead of `cvLoss`. The alternative can save time if you are going to examine the cross-validated tree more than once.

However, unlike `cvLoss`, `kfoldLoss` does not return `SE`, `Nleaf`, or `BestLevel`. `kfoldLoss` also does not allow you to examine any error other than classification error.

See Also

`ClassificationTree.fit` | `crossval` | `loss` | `kfoldLoss`

RegressionTree.cvLoss

Purpose Regression error by cross validation

Syntax

```
E = cvLoss(tree)
[E,SE] = cvLoss(tree)
[E,SE,Nleaf] = cvLoss(tree)
[E,SE,Nleaf,BestLevel] = cvLoss(tree)
[E,...] = cvLoss(tree,Name,Value)
```

Description

`E = cvLoss(tree)` returns the cross-validated regression error (loss) for `tree`, a regression tree.

`[E,SE] = cvLoss(tree)` returns the standard error of `E`.

`[E,SE,Nleaf] = cvLoss(tree)` returns the number of leaves (terminal nodes) in `tree`.

`[E,SE,Nleaf,BestLevel] = cvLoss(tree)` returns the optimal pruning level for `tree`.

`[E,...] = cvLoss(tree,Name,Value)` cross validates with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

tree

A regression tree produced by `RegressionTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

subtrees

Vector of pruning levels, with 0 representing the full, unpruned tree. `tree` must include a pruning sequence as created either by

ClassificationTree.fit with 'prune' set to 'on', or by the prune method. The returned E, SE, and Nleaf are vectors of the same length as subtrees; BestLevel is a scalar. If you set subtrees to 'all', cvLoss uses the entire pruning sequence.

Default: 0

treesize

One of the following strings:

- 'se' — cvLoss uses the smallest tree whose cost is within one standard error of the minimum cost.
- 'min' — cvLoss uses the minimal cost tree.

Default: 'se'

kfold

Number of cross-validation samples, a positive integer.

Default: 10

Output Arguments

E

The cross-validation mean squared error (loss). A vector or scalar depending on the setting of the subtrees name-value pair.

SE

The standard error of E. A vector or scalar depending on the setting of the subtrees name-value pair.

Nleaf

Number of leaf nodes in tree. Leaf nodes are terminal nodes, which give responses, not splits. A vector or scalar depending on the setting of the subtrees name-value pair.

BestLevel

RegressionTree.cvLoss

By default, a scalar representing the largest pruning level that achieves a value of `E` within `SE` of the minimum error. If you set `treesize` to `'min'`, `BestLevel` is the smallest value in subtrees.

Examples

Compute the cross-validation error for the default classification tree for the `carsmall` data:

```
load carsmall
X = [Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
[E,SE,Nleaf,BestLevel] = cvLoss(tree)
```

```
E =
    30.7558
```

```
SE =
    6.0651
```

```
Nleaf =
    19
```

```
BestLevel =
    0
```

Find the best level by using the `subtrees` name-value pair:

```
[~,~,~,BestLevel] = cvLoss(tree,'subtrees','all')
```

```
BestLevel =
    15
```

Alternatives

You can construct a cross-validated tree model with `crossval`, and call `kfoldLoss` instead of `cvLoss`. The alternative can save time if you are going to examine the cross-validated tree more than once.

However, unlike `cvLoss`, `kfoldLoss` does not return `SE`, `Nleaf`, or `BestLevel`.

See Also

[crossval](#) | [kfoldLoss](#) | [RegressionTree.fit](#) | [loss](#)

cvpartition

Purpose	Data partitions for cross validation	
Description	An object of the <code>cvpartition</code> class defines a random partition on a set of data of a specified size. Use this partition to define test and training sets for validating a statistical model using cross validation.	
Construction	<code>cvpartition</code>	Create cross validation partition for data
Methods	<code>disp</code>	Display <code>cvpartition</code> object
	<code>display</code>	Display <code>cvpartition</code> object
	<code>repartition</code>	Repartition data for cross-validation
	<code>test</code>	Test indices for cross-validation
	<code>training</code>	Training indices for cross-validation
Properties	<code>N</code>	Number of observations (including observations with missing group values)
	<code>NumTestSets</code>	Number of test sets
	<code>TestSize</code>	Size of each test set
	<code>TrainSize</code>	Size of each training set
	<code>Type</code>	Type of partition
Copy Semantics	Value. To learn how this affects your use of the class, see Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation .	

Examples

Use a 10-fold stratified cross validation to compute the misclassification error for `classify` on iris data.

```
load('fisheriris');
CVO = cvpartition(species,'k',10);
err = zeros(CVO.NumTestSets,1);
for i = 1:CVO.NumTestSets
    trIdx = CVO.training(i);
    teIdx = CVO.test(i);
    ytest = classify(meas(teIdx,:),meas(trIdx,:),...
    species(trIdx,:));
    err(i) = sum(~strcmp(ytest,species(teIdx)));
end
cvErr = sum(err)/sum(CVO.TestSize);
```

See Also

`crossval`

How To

• “Grouping Variables” on page 2-72

cvpartition

Purpose Create cross validation partition for data

Syntax

```
c = cvpartition(n, 'kfold', k)
c = cvpartition(group, 'kfold', k)
c = cvpartition(n, 'holdout', p)
c = cvpartition(group, 'holdout', p)
c = cvpartition(n, 'leaveout')
c = cvpartition(n, 'resubstitution')
```

Description

`c = cvpartition(n, 'kfold', k)` constructs an object `c` of the `cvpartition` class defining a random partition for `k`-fold cross validation on `n` observations. The partition divides the observations into `k` disjoint subsamples (or *folds*), chosen randomly but with roughly equal size. The default value of `k` is 10.

`c = cvpartition(group, 'kfold', k)` creates a random partition for a stratified `k`-fold cross validation. `group` is a numeric vector, categorical array, string array, or cell array of strings indicating the class of each observation. Each subsample has roughly equal size and roughly the same class proportions as in `group`. `cvpartition` treats NaNs or empty strings in `group` as missing values.

`c = cvpartition(n, 'holdout', p)` creates a random partition for holdout validation on `n` observations. This partition divides the observations into a training set and a test (or *holdout*) set. The parameter `p` must be a scalar. When $0 < p < 1$, `cvpartition` randomly selects approximately $p \cdot n$ observations for the test set. When `p` is an integer, `cvpartition` randomly selects `p` observations for the test set. The default value of `p` is 1/10.

`c = cvpartition(group, 'holdout', p)` randomly partitions observations into a training set and a test set with stratification, using the class information in `group`; that is, both training and test sets have roughly the same class proportions as in `group`.

`c = cvpartition(n, 'leaveout')` creates a random partition for leave-one-out cross validation on `n` observations. Leave-one-out is a special case of 'kfold', in which the number of folds equals the number of observations.

`c = cvpartition(n, 'resubstitution')` creates an object `c` that does not partition the data. Both the training set and the test set contain all of the original `n` observations.

Examples

Use stratified 10-fold cross validation to compute misclassification rate:

```
load fisheriris;
y = species;
c = cvpartition(y, 'k', 10);

fun = @(xT,yT,xt,yt)(sum(~strcmp(yt,classify(xt,xT,yT))));

rate = sum(crossval(fun,meas,y,'partition',c)...
           /sum(c.TestSize)
rate =
    0.0200
```

See Also

`crossval` | `repartition`

How To

- “Grouping Variables” on page 2-72

ClassificationDiscriminant.cvshrink

Purpose Cross-validate regularization of linear discriminant

Syntax

```
err = cvshrink(obj)
[err,gamma] = cvshrink(obj)
[err,gamma,delta] = cvshrink(obj)
[err,gamma,delta,numpred] = cvshrink(obj)
[err,...] = cvshrink(obj,Name,Value)
```

Description `err = cvshrink(obj)` returns a vector of cross-validated classification error values for differing values of the regularization parameter Gamma.

`[err,gamma] = cvshrink(obj)` also returns the vector of Gamma values.

`[err,gamma,delta] = cvshrink(obj)` also returns the vector of Delta values.

`[err,gamma,delta,numpred] = cvshrink(obj)` returns the vector of number of nonzero predictors for each setting of the parameters Gamma and Delta.

`[err,...] = cvshrink(obj,Name,Value)` cross validates with additional options specified by one or more Name,Value pair arguments.

Tips

- Examine the `err` and `numpred` outputs to see the tradeoff between cross-validated error and number of predictors. When you find a satisfactory point, set the corresponding `gamma` and `delta` properties in the model by dot addressing. For example, if (i, j) is the location of the satisfactory point, set

```
obj.Gamma = gamma(i);
obj.Delta = delta(i,j);
```

Input Arguments

obj Discriminant analysis classifier, produced using `ClassificationDiscriminant.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, . . . , NameN, ValueN`.

delta

- **Scalar delta** — `cvshrink` uses this value of `delta` with every value of `gamma` for regularization.
- **Row vector delta** — For each `i` and `j`, `cvshrink` uses `delta(j)` with `gamma(i)` for regularization.
- **Matrix delta** — The number of rows of `delta` must equal the number of elements in `gamma`. For each `i` and `j`, `cvshrink` uses `delta(i, j)` with `gamma(i)` for regularization.

Default: 0

gamma

Vector of `Gamma` values for cross-validation.

Default: 0:0.1:1

NumDelta

Number of `Delta` intervals for cross-validation. For every value of `Gamma`, `cvshrink` cross-validates the discriminant using `NumDelta + 1` values of `Delta`, uniformly spaced from zero to the maximal `Delta` at which all predictors are eliminated for this value of `Gamma`. If you set `delta`, `cvshrink` ignores `NumDelta`.

Default: 0

NumGamma

ClassificationDiscriminant.cvshrink

Number of Gamma intervals for cross-validation. `cvshrink` cross-validates the discriminant using `NumGamma + 1` values of Gamma, uniformly spaced from `MinGamma` to 1. If you set `gamma`, `cvshrink` ignores `NumGamma`.

Default: 10

verbose

Verbosity level, an integer from 0 to 2. Higher values give more progress messages.

Default: 0

Output Arguments

err

Numeric vector or matrix of errors. `err` is the misclassification error rate, meaning the average fraction of misclassified data over all folds.

- If `delta` is a scalar (default), `err(i)` is the misclassification error rate for `obj` regularized with `gamma(i)`.
- If `delta` is a vector, `err(i,j)` is the misclassification error rate for `obj` regularized with `gamma(i)` and `delta(j)`.
- If `delta` is a matrix, `err(i,j)` is the misclassification error rate for `obj` regularized with `gamma(i)` and `delta(i,j)`.

gamma

Vector of Gamma values used for regularization. See “Gamma and Delta” on page 20-457.

delta

Vector or matrix of Delta values used for regularization. See “Gamma and Delta” on page 20-457.

- If you give a scalar for the `delta` name-value pair, the output `delta` is a row vector the same size as `gamma`, with entries equal to the input scalar.
- If you give a row vector for the `delta` name-value pair, the output `delta` is a matrix with the same number of columns as the row vector, and with the number of rows equal to the number of elements of `gamma`. The output `delta(i, j)` is equal to the input `delta(j)`.
- If you give a matrix for the `delta` name-value pair, the output `delta` is the same as the input matrix. The number of rows of `delta` must equal the number of elements in `gamma`.

numpred

Numeric vector or matrix containing the number of predictors in the model at various regularizations. `numpred` has the same size as `err`.

- If `delta` is a scalar (default), `numpred(i)` is the number of predictors for `obj` regularized with `gamma(i)` and `delta`.
- If `delta` is a vector, `numpred(i, j)` is the number of predictors for `obj` regularized with `gamma(i)` and `delta(j)`.
- If `delta` is a matrix, `numpred(i, j)` is the number of predictors for `obj` regularized with `gamma(i)` and `delta(i, j)`.

Definitions

Gamma and Delta

Regularization is the process of finding a small set of predictors that yield an effective predictive model. For linear discriminant analysis, there are two parameters, γ and δ , that control regularization as follows. `cvshrink` helps you select appropriate values of the parameters.

Let Σ represent the covariance matrix of the data X , and let \hat{X} be the centered data (the data X minus the mean by class). Define

ClassificationDiscriminant.cvshrink

$$D = \text{diag}(\hat{X}^T * \hat{X}).$$

The regularized covariance matrix $\tilde{\Sigma}$ is

$$\tilde{\Sigma} = (1 - \gamma)\Sigma + \gamma D.$$

Whenever $\gamma \geq \text{MinGamma}$, $\tilde{\Sigma}$ is nonsingular.

Let μ_k be the mean vector for those elements of X in class k , and let μ_0 be the global mean vector (the mean of the rows of X). Let C be the correlation matrix of the data X , and let \tilde{C} be the regularized correlation matrix:

$$\tilde{C} = (1 - \gamma)C + \gamma I,$$

where I is the identity matrix.

The linear term in the regularized discriminant analysis classifier for a data point x is

$$(x - \mu_0)^T \tilde{\Sigma}^{-1} (\mu_k - \mu_0) = \left[(x - \mu_0)^T D^{-1/2} \right] \left[\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right].$$

The parameter δ enters into this equation as a threshold on the final term in square brackets. Each component of the vector

$\left[\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right]$ is set to zero if it is smaller in magnitude than the threshold δ . Therefore, for class k , if component j is thresholded to zero, component j of x does not enter into the evaluation of the posterior probability.

The `DeltaPredictor` property is a vector related to this threshold. When $\delta \geq \text{DeltaPredictor}(i)$, all classes k have

$$\left| \tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0) \right| \leq \delta.$$

Therefore, when $\delta \geq \text{DeltaPredictor}(i)$, the regularized classifier does not use predictor i .

Examples

Regularize Data with Many Predictors

This example shows how to regularize a discriminant analysis classifier, and how to view the tradeoff between the number of predictors in the model and the classification accuracy.

Create a linear discriminant analysis classifier for the ovariancancer data. Set the `SaveMemory` and `FillCoeffs` options to keep the resulting model reasonably small.

```
load ovariancancer
obj = ClassificationDiscriminant.fit(obs,grp,...
    'SaveMemory','on','FillCoeffs','off');
```

Use 10 levels of `Gamma` and 10 levels of `Delta` to search for good parameters. This search is time-consuming. Set `Verbose` to 1 to view the progress.

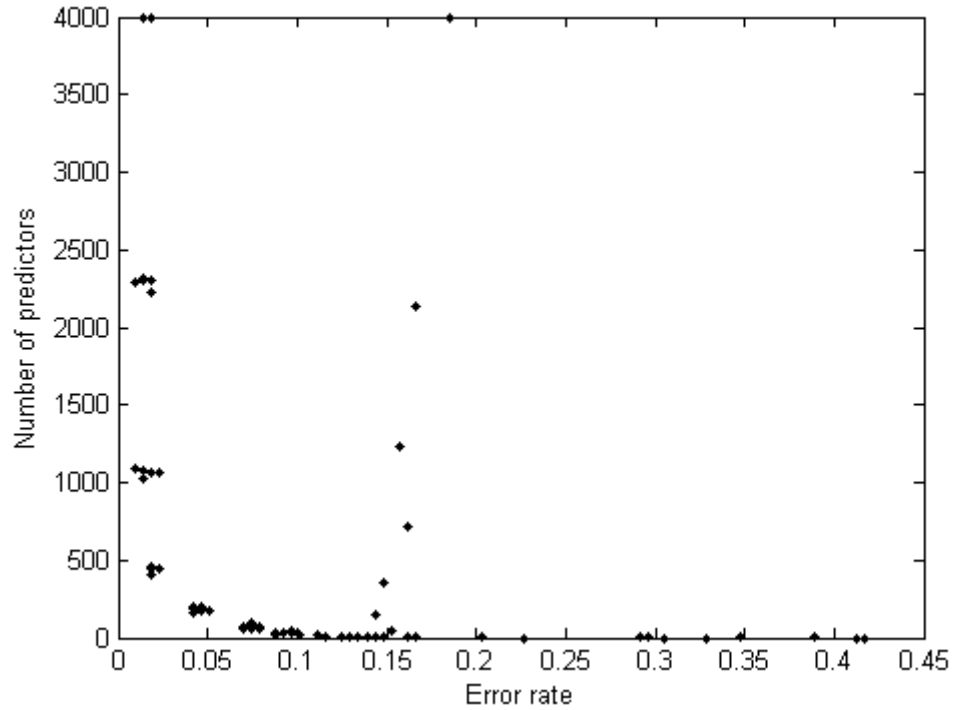
```
rng('default') % for reproducibility
[err,gamma,delta,numpred] = cvshrink(obj,...
    'NumGamma',9,'NumDelta',9,'Verbose',1);
```

```
Done building cross-validated model.
Processing Gamma step 1 out of 10.
Processing Gamma step 2 out of 10.
Processing Gamma step 3 out of 10.
Processing Gamma step 4 out of 10.
Processing Gamma step 5 out of 10.
Processing Gamma step 6 out of 10.
Processing Gamma step 7 out of 10.
Processing Gamma step 8 out of 10.
Processing Gamma step 9 out of 10.
Processing Gamma step 10 out of 10.
```

Plot the classification error rate against the number of predictors.

```
plot(err,numpred,'k.')
xlabel('Error rate');
ylabel('Number of predictors');
```

ClassificationDiscriminant.cvshrink



See Also

[ClassificationDiscriminant](#) | [ClassificationDiscriminant.fit](#) |

Related Examples

- “Regularize a Discriminant Analysis Classifier” on page 12-22

Concepts

- “Discriminant Analysis” on page 12-3

Purpose Cross validate shrinking (pruning) ensemble

Syntax

```
vals = cvshrink(ens)
[vals,nlearn] = cvshrink(ens)
[vals,nlearn] = cvshrink(ens,Name,Value)
```

Description `vals = cvshrink(ens)` returns an L-by-T matrix with cross-validated values of the mean squared error. L is the number of `lambda` values in the `ens.Regularization` structure. T is the number of `threshold` values on weak learner weights. If `ens` does not have a `Regularization` property filled in by the `regularize` method, pass a `lambda` name-value pair.

`[vals,nlearn] = cvshrink(ens)` returns an L-by-T matrix of the mean number of learners in the cross-validated ensemble.

`[vals,nlearn] = cvshrink(ens,Name,Value)` cross validates with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

ens

A regression ensemble, created with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

cvpartition

A partition created with `cvpartition` to use in a cross-validated tree. You can only use one of these four options at a time: `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`.

holdout

RegressionEnsemble.cvshrink

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer. If you do not supply a cross-validation method, `cvshrink` uses 10-fold cross validation. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

lambda

Vector of nonnegative regularization parameter values for lasso. If empty, `cvshrink` does not perform cross validation.

Default: []

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

threshold

Numeric vector with lower cutoffs on weights for weak learners. `cvshrink` discards learners with weights below `threshold` in its cross-validation calculation.

Default: 0

Output Arguments

vals

L-by-T matrix with cross-validated values of the mean squared error. L is the number of values of the regularization parameter

'lambda', and T is the number of 'threshold' values on weak learner weights.

nlearn

L-by-T matrix with cross-validated values of the mean number of learners in the cross-validated ensemble. L is the number of values of the regularization parameter 'lambda', and T is the number of 'threshold' values on weak learner weights.

Examples

Create a regression ensemble for predicting mileage from the `carsmall` data. Cross validate the ensemble for three values each of `lambda` and `threshold`.

```
load carsmall
X = [Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'bag',100,'Tree',...
    'type','regression');
[vals nlearn] = cvshrink(ens,'lambda',[.01 .1 1],...
    'threshold',[0 .01 .1])

vals =
    20.0949    19.9007    131.6316
    20.0924    19.8431    128.0989
    19.9759    19.7987    119.5574

nlearn =
    13.3000    11.6000     3.5000
    13.2000    11.5000     3.6000
    13.4000    11.4000     3.9000
```

Clearly, setting a threshold of 0.1 leads to unacceptable errors, while a threshold of 0.01 gives similar errors to a threshold of 0. The mean number of learners with a threshold of 0.1 is about 11.5, whereas the mean number is about 13.2 when the threshold is 0.

See Also

`regularize` | `shrink`

datasample

Purpose Randomly sample from data, with or without replacement

Syntax

```
y = datasample(data,k)
y = datasample(data,k,dim)
[y,idx] = datasample(data,k,...)
[y,...] = datasample(s,data,k,...)
[y,...] = datasample(data,k,Name,Value)
[y,...] = datasample(data,k,dim,Name,Value)
```

Description `y = datasample(data,k)` returns `k` observations sampled uniformly at random, with replacement, from the data in `data`.

`y = datasample(data,k,dim)` returns a sample taken along dimension `dim` of `data`.

`[y,idx] = datasample(data,k,...)` returns an index vector indicating which values `datasample` sampled from `data`.

`[y,...] = datasample(s,data,k,...)` uses the random number stream `s` to generate random numbers.

`[y,...] = datasample(data,k,Name,Value)` or `[y,...] = datasample(data,k,dim,Name,Value)` samples with additional options specified by one or more `Name,Value` pair arguments.

- Tips**
- To sample random integers with replacement from a range, use `randi`.
 - To sample random integers without replacement, use `randperm` or `datasample`.
 - To randomly sample from data, with or without replacement, use `datasample`.

Input Arguments

data
Vector, matrix, N -dimensional array, or dataset array representing the data from which to sample. By default, `datasample` regards the rows of a data matrix, or the first nonsingleton dimension of a `data` array, as data elements. Change this behavior with the `dim` argument.

k

Positive integer, the number of samples.

dim

Integer specifying the dimension on which to take samples. For example, if `data` is a matrix and `dim` is 2, `y` contains a selection of columns in `data`. If `data` is a dataset array and `dim` is 2, `y` contains a selection of variables in `data`. Use `dim` to ensure sampling along a specific dimension regardless of whether `data` is a vector, matrix or N -dimensional array.

Default: 1

s

Random number stream. Create `s` using `rng` or `RandStream`.

Default: The global random number stream

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Replace

Select the sample with replacement if `Replace` is true, or without replacement if `Replace` is false. If `Replace` is false, `k` must not be larger than the number of data elements in `data`.

Default: true

Weights

datasample

Vector with the same number of elements as data elements in `data`, and with nonnegative elements. Sample with probability proportional to the elements of `Weights`.

Default: `ones(datasize,1)`, where `datasize` is the number of data elements in `data`

Output Arguments

y

- If `data` is a vector, `y` is a vector containing `k` elements selected from `data`.
- If `data` is a matrix, `y` is a matrix containing `k` rows selected from `data`. Or, if `dim = 2`, `y` is a matrix containing `k` columns selected from `data`
- If `data` is an N -dimensional array, `datasample` samples along its first non-singleton dimension. Or, if you give a `dim` name-value pair, `datasample` samples along the dimension `dim`.

When the sample is taken with replacement (default), `y` can contain repeated observations from `data`. Set the `Replace` name-value pair to `false` to sample without replacement.

idx

Vector of indices indicating which elements `datasample` chose from `data` to create `y`. For example:

- If `data` is a vector, `y = data(idx)`.
- If `data` is a matrix, `y = data(idx,:)`.

Examples

Draw five unique values from the integers `1:10`.

```
y = datasample(1:10,5,'Replace',false)
```

```
y =  
     6     3     7     8     5
```

Generate a random sequence of the characters ACGT, with replacement, according to specified probabilities.

```
seq = datasample('ACGT',48,'Weights',[0.15 0.35 0.35 0.15])

seq =
CTTCGACTGTGAGTGGGCGCGACAAGGCTACCGGCCCGGGCGGGCACTC
```

Select a random subset of columns from a data matrix.

```
X = randn(10,1000);
Y = datasample(X,5,2,'Replace',false)
```

```
Y =
    0.7007    0.3382    2.1298   -0.1891    0.5026
    0.6520   -0.6693   -0.1961   -0.9915    1.9107
    0.1785    0.6640    2.3247   -1.1735   -1.0020
    1.6760    2.6102   -0.8902   -0.7735    1.8676
   -0.3251   -0.6415   -0.2572   -0.1629   -1.0523
    0.1011    0.9323   -1.3088   -0.4477    0.8036
   -0.5767   -0.5778   -0.8556    0.8672   -0.0727
   -0.0615   -0.9084    0.9020   -0.4185   -1.9520
    0.7256   -1.1228    0.7558    1.2691    2.4997
   -1.2273    0.5754   -0.8755   -0.8224   -1.2066
```

Resample observations from a dataset array to create a bootstrap replicate dataset.

```
load hospital
y = datasample(hospital,size(hospital,1));
```

Use the second output to sample “in parallel” from two data vectors.

```
x1 = randn(100,1);
```

datasample

```
x2 = randn(100,1);  
[y1,idx] = datasample(x1,10);  
y2 = x2(idx);
```

Algorithms

`datasample` uses `randperm`, `rand`, or `randi` to generate random values. Therefore, `datasample` changes the state of the MATLAB global random number generator. Control the random number generator using `rng`.

For selecting weighted samples without replacement, `datasample` uses the algorithm of Wong and Easton [1].

References

[1] Wong, C. K. and M. C. Easton. *An Efficient Method for Weighted Sampling Without Replacement*. *SIAM Journal of Computing* 9(1), pp. 111–113, 1980.

Alternatives

You can use `randi` or `randperm` to generate indices for random sampling with or without replacement, respectively. However, `datasample` can be more convenient because it samples directly from your data. `datasample` also allows weighted sampling.

See Also

`rand` | `randi` | `randperm` | `RandStream` | `rng`

Purpose

Arrays for statistical data

Description

Dataset arrays are used to collect heterogeneous data and metadata including variable and observation names into a single container variable. Dataset arrays are suitable for storing column-oriented or tabular data that are often stored as columns in a text file or in a spreadsheet, and can accommodate variables of different types, sizes, units, etc.

Dataset arrays can contain different kinds of variables, including numeric, logical, character, categorical, and cell. However, a dataset array is a different class than the variables that it contains. For example, even a dataset array that contains only variables that are double arrays cannot be operated on as if it were itself a double array. However, using dot subscripting, you can operate on variable in a dataset array as if it were a workspace variable.

You can subscript dataset arrays using parentheses much like ordinary numeric arrays, but in addition to numeric and logical indices, you can use variable and observation names as indices.

Construction

Use the `dataset` constructor to create a dataset array from variables in the MATLAB workspace. You can also create a dataset array by reading data from a text or spreadsheet file. You can access each variable in a dataset array much like fields in a structure, using dot subscripting. See the following section for a list of operations available for dataset arrays.

<code>dataset</code>	Construct dataset array
----------------------	-------------------------

Methods

<code>cat</code>	Concatenate dataset arrays
------------------	----------------------------

<code>cellstr</code>	Create cell array of strings from dataset array
----------------------	---

<code>dataset2cell</code>	Convert dataset array to cell array
---------------------------	-------------------------------------

dataset

dataset2struct	Convert dataset array to structure
datasetfun	Apply function to dataset array variables
disp	Display dataset array
display	Display dataset array
double	Convert dataset variables to double array
end	Last index in indexing expression for dataset array
export	Write dataset array to file
get	Access dataset array properties
horzcat	Horizontal concatenation for dataset arrays
intersect	Set intersection for dataset array observations
isempty	True for empty dataset array
ismember	Dataset array elements that are members of set
ismissing	Find dataset array elements with missing values
join	Merge observations
length	Length of dataset array
ndims	Number of dimensions of dataset array
numel	Number of elements in dataset array
replacedata	Replace dataset variables

<code>replaceWithMissing</code>	Insert missing data indicators into a dataset array
<code>set</code>	Set and display properties
<code>setdiff</code>	Set difference for dataset array observations
<code>setxor</code>	Set exclusive or for dataset array observations
<code>single</code>	Convert dataset variables to single array
<code>size</code>	Size of dataset array
<code>sortrows</code>	Sort rows of dataset array
<code>stack</code>	Stack data from multiple variables into single variable
<code>subsasgn</code>	Subscripted assignment to dataset array
<code>subsref</code>	Subscripted reference for dataset array
<code>summary</code>	Print summary of dataset array
<code>union</code>	Set union for dataset array observations
<code>unique</code>	Unique observations in dataset array
<code>unstack</code>	Unstack data from single variable into multiple variables
<code>vertcat</code>	Vertical concatenation for dataset arrays

Properties

A dataset array `D` has properties that store metadata (information about your data). Access or assign to a property using `P =`

`D.Properties.PropName` or `D.Properties.PropName = P`, where `PropName` is one of the following:

Description	String describing data set
DimNames	Two-element cell array of strings giving names of dimensions of data set
ObsNames	Cell array of nonempty, distinct strings giving names of observations in data set
Units	Units of variables in data set
UserData	Variable containing additional information associated with data set
VarDescription	Cell array of strings giving descriptions of variables in data set
VarNames	Cell array giving names of variables in data set

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

Examples

Load a dataset array from a `.mat` file and create some simple subsets:

```
load hospital
h1 = hospital(1:10,:)
h2 = hospital(:, {'LastName' 'Age' 'Sex' 'Smoker'})

% Access and modify metadata
hospital.Properties.Description
hospital.Properties.VarNames{4} = 'Wgt'
```

```
% Create a new dataset variable from an existing one
hospital.AtRisk = hospital.Smoker | (hospital.Age > 40)

% Use individual variables to explore the data
boxplot(hospital.Age,hospital.Sex)
h3 = hospital(hospital.Age<30,...
    {'LastName' 'Age' 'Sex' 'Smoker'})

% Sort the observations based on two variables
h4 = sortrows(hospital,{'Sex','Age'})
```

See Also

genvarname | tdfread | textscan | xlsread

How To

- “Dataset Arrays” on page 2-22

dataset

Purpose Construct dataset array

Syntax

```
A = dataset(varspec, 'ParamName', Value)
A = dataset('File', filename, 'ParamName', Value)
A = dataset('XLSFile', filename, 'ParamName', Value)
A = dataset('XPTFile', xptfilename, 'ParamName', Value)
```

Description `A = dataset(varspec, 'ParamName', Value)` creates dataset array `A` using the workspace variable input method `varspec` and one or more optional name/value pairs (see Parameter Name/Value Pairs).

The input method `varspec` can be one or more of the following:

- `VAR` — a workspace variable. `dataset` uses the workspace name for the variable name in `A`. To include multiple variables, specify `VAR_1, VAR_2, ..., VAR_N`. Variables can be arrays of any size, but all variables must have the same number of rows. `VAR` can also be an expression. In this case, `dataset` creates a default name automatically.
- `{VAR, name}` — a workspace variable, `VAR` and a variable name, `name`. `dataset` uses `name` as the variable name. To include multiple variables and names, specify `{VAR_1, name_1}`, `{VAR_2, name_2}`, ..., `{VAR_N, name_N}`.
- `{VAR, name_1, ..., name_m}` — an `m`-columned workspace variable, `VAR`. `dataset` uses the names `name_1, ..., name_m` as variable names. You must include a name for every column in `VAR`. Each column becomes a separate variable in `A`.

You can combine these input methods to include as many variables and names as needed. Names must be valid, unique MATLAB identifier strings. For example input combinations, see Examples. For optional name/value pairs see Inputs.

To convert numeric arrays, cell arrays, or structure arrays to dataset arrays, you can also use (respectively):

- `mat2dataset`

- `cell2dataset`
- `struct2dataset`

Note Dataset arrays may contain built-in types or array objects as variables. Array objects must implement each of the following:

- Standard MATLAB parenthesis indexing of the form `var(i,...)`, where `i` is a numeric or logical vector corresponding to rows of the variable
- A `size` method with a `dim` argument
- A `vertcat` method

`A = dataset('File',filename,'ParamName',Value)` creates dataset array `A` from column-oriented data in the text file specified by the string `filename`. Variables in `A` are of type `double` if data in the corresponding column of the file, following the column header, are entirely numeric; otherwise the variables in `A` are cell arrays of strings. `dataset` converts empty fields to either `NaN` (for a numeric variable) or the empty string (for a string-valued variable). `dataset` ignores insignificant white space in the file. You cannot specify both a file and workspace variables as input. See Name/Value Pairs for more information.

`A = dataset('XLSFile',filename,'ParamName',Value)` creates dataset array `A` from column-oriented data in the Excel spreadsheet specified by the string `filename`. Variables in `A` are of type `double` if data in the corresponding column of the spreadsheet, following the column header, are entirely numeric; otherwise the variables in `A` are cell arrays of strings. See Name/Value Pairs for more information.

`A = dataset('XPTFile',xptfilename,'ParamName',Value)` creates a dataset array from a SAS® XPORT format file. Variable names from the XPORT format file are preserved. Numeric data types in the XPORT format file are preserved but all other data types are converted to cell

arrays of strings. The XPORT format allows for 28 missing data types. `dataset` represents these in the file by an upper case letter, '.' or '_'. `dataset` converts all missing data to NaN values in `A`. However, if you need the specific missing types you can use the `xptread` function to recover the information. See Name/Value Pairs for more information.

Parameter Name/Value Pairs

Specify one or more of the following name/value pairs when constructing a dataset:

VarNames

A cell array `{name_1, ..., name_m}` naming the `m` variables in `A` with the specified variable names. Names must be valid, unique MATLAB identifier strings. The number of names must equal the number of variables in `A`. You cannot use the `VarNames` parameter if you provide names for individual variables using `{VAR, name}` pairs. To specify `VarNames` when using a file as input, set `ReadVarNames` to `false`.

ObsNames

A cell array `{name_1, ..., name_n}` naming the `n` observations in `A` with the specified observation names. The names need not be valid MATLAB identifier strings, but must be unique. The number of names must equal the number of observations (rows) in `A`. To specify `ObsNames` when using a file as input, set `ReadObsNames` to `false`.

Name/value pairs available when using text files as inputs:

Delimiter

A string indicating the character separating columns in the file. Values are

- '\t' (tab, the default when no format is specified)
- ' ' (space, the default when a format is specified)
- ',' (comma)

- ';' (semicolon)
- '|' (bar)

Format

A format string, as accepted by `textscan`. `dataset` reads the file using `textscan`, and creates variables in `A` according to the conversion specifiers in the format string. You may also provide any name/value pairs accepted by `textscan`. Using the `Format` parameter is much faster for large files. If `ReadObsNames` is `true`, the format string should include a format specifier for the first column of the file.

HeaderLines

Numeric value indicating the number of lines to skip at the beginning of a file.

Default: 0

TreatAsEmpty

Specifies strings to treat as the empty string in a numeric column. Values may be a character string or a cell array of strings. The parameter applies only to numeric columns in the file; `dataset` does not accept numeric literals such as `'-99'`.

Name/value pairs available when using text files or Excel spreadsheets as inputs:**ReadVarNames**

A logical value indicating whether (`true`) or not (`false`) to read variable names from the first row of the file. The default is `true`. If `ReadVarNames` is `true`, variable names in the column headers of the file or range (if using an Excel spreadsheet) cannot be empty.

ReadObsNames

dataset

A logical value indicating whether (`true`) or not (`false`) to read observation names from the first column of the file or range (if using an Excel spreadsheet). The default is `false`. If `ReadObsNames` and `ReadVarNames` are both `true`, `dataset` saves the header of the first column in the file or range as the name of the first dimension in `A.Properties.DimNames`.

When reading from an XPT format file, the `ReadObsNames` parameter name/value pair determines whether or not to try to use the first variable in the file as observation names. Specify as a logical value (default `false`). If the contents of the first variable are not valid observation names then `dataset` reads the variable into a variable of the dataset array and does not set the observation names.

Name/value pairs available when using Excel spreadsheets as input:

Sheet

A positive scalar value of type `double` indicating the sheet number, or a quoted string indicating the sheet name.

Range

A string of the form `'C1:C2'` where `C1` and `C2` are the names of cells at opposing corners of a rectangular region to be read, as for `xlsread`. By default, the rectangular region extends to the right-most column containing data. If the spreadsheet contains empty columns between columns of data, or if the spreadsheet contains figures or other non-tabular information, specify a range that contains only data.

Examples

Create a dataset array from workspace variables, including observation names:

```
load cereal
cereal = dataset(Calories,Protein,Fat,Sodium,Fiber,Carbo,...
    Sugars,'ObsNames',Name)
```



```
cereal.Properties.VarDescription = Variables(4:10,2);
```

Create a dataset array from a single, multi-columned workspace variable, designating variable names for each column:

```
load cities
categories = cellstr(categories);
cities = dataset({ratings, categories{:}}, ...
    'ObsNames', cellstr(names))
```

Load data from a text or spreadsheet file

```
patients = dataset('File', 'hospital.dat', ...
    'Delimiter', ',', 'ReadObsNames', true)
patients2 = dataset('XLSFile', 'hospital.xls', ...
    'ReadObsNames', true)
```

- 1 Load patient data from the CSV file `hospital.dat` and store the information in a dataset array with observation names given by the first column in the data (patient identification):

```
patients = dataset('file', 'hospital.dat', ...
    'format', '%s%s%s%f%f%f%f%f%f%f', ...
    'Delimiter', ',', 'ReadObsNames', true);
```

You can also load the data without specifying a format string. `dataset` will automatically create dataset variables that are either double arrays or cell arrays of strings, depending on the contents of the file:

```
patients = dataset('file', 'hospital.dat', ...
    'delimiter', ',', ...
    'ReadObsNames', true);
```

- 2 Make the {0,1}-valued variable `smoke` nominal, and change the labels to 'No' and 'Yes':

```
patients.smoke = nominal(patients.smoke, {'No', 'Yes'});
```

- 3 Add new levels to `smoke` as placeholders for more detailed histories of smokers:

```
patients.smoke = addlevels(patients.smoke, ...  
                           {'0-5 Years', '5-10 Years', 'LongTerm'});
```

- 4 Assuming the nonsmokers have never smoked, relabel the 'No' level:

```
patients.smoke = setlabels(patients.smoke, 'Never', 'No');
```

- 5 Drop the undifferentiated 'Yes' level from `smoke`:

```
patients.smoke = droplevels(patients.smoke, 'Yes');
```

Warning: OLDLEVELS contains categorical levels that were present in A, caused some array elements to have undefined levels.

Note that smokers now have an undefined level.

- 6 Set each smoker to one of the new levels, by observation name:

```
patients.smoke('YPL-320') = '5-10 Years';
```

See Also

[cell2dataset](#) | [mat2dataset](#) | [struct2dataset](#) | [tdfread](#) | [textscan](#) | [xlsread](#)

Related Examples

- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Create a Dataset Array from a File” on page 2-92
- “Dataset Arrays in the Variables Editor” on page 2-143

Concepts

- “Dataset Arrays” on page 2-156

Purpose Convert dataset array to cell array

Syntax `C = dataset2cell(D)`

Description `C = dataset2cell(D)` converts the dataset array `D` to a cell array `C`. Each variable of `D` becomes a column in `C`. If `D` is an `M`-by-`N` array, then `C` is `(M+1)`-by-`N`, with the variable names of `D` in the first row. If `D` contains observation names, then `C` is `(M+1)`-by-`(N+1)`, with the observation names in the first column.

See Also `dataset` | `dataset.export`

dataset.dataset2struct

Purpose Convert dataset array to structure

Syntax
`S = dataset2struct(D)`
`S = dataset2struct(D, 'AsScalar', true)`

Description `S = dataset2struct(D)` converts a dataset array to a structure array. Each variable of `D` becomes a field in `S`. If `D` is an M -by- N dataset array, then `S` is M -by-1 and has N fields. If `D` contains observation names, then `S` contains those names in the additional field `ObsNames`.

`S = dataset2struct(D, 'AsScalar', true)` converts a dataset array to a scalar structure. Each variable of `D` becomes a field in `S`. If `D` is an M -by- N dataset array, then `S` has N fields, each of which as M rows. If `D` contains observation names, then `S` contains those names in the additional field `ObsNames`.

Input Arguments **D**
 M -by- N dataset array.

Output Arguments **s**
 M -by-1 structure array, with N fields. If the input dataset array contains observation names, then `S` has an additional field `ObsNames`.
If you specify `'AsScalar', true`, then `S` is a scalar structure, with N fields, each with M rows.

Examples **Convert Dataset Array to Structure Array**

Load sample dataset array.

```
load('hospital')
```

Create a dataset array, `D`, that has only a subset of the observations and variables.

```
D = hospital(1:8, {'LastName', 'Sex', 'Age'});
```

```
size(D)

ans =

     8     3
```

The dataset array D has 8 observations and 3 variables.

Convert D to a structure array.

```
S = dataset2struct(D)

S =

8x1 struct array with fields:
    ObsNames
    LastName
    Sex
    Age
```

The structure is 8x1, corresponding to the 8 observations in the dataset array. S also has the field `ObsNames`, since D had observation names.

Display the field data for the first element of S.

```
S(1)

ans =

    ObsNames: 'YPL-320'
    LastName: 'SMITH'
           Sex: [1x1 nominal]
           Age: 38
```

This information corresponds to the first observation (row) of the dataset array.

Convert Dataset Array to Scalar Structure

Load sample dataset array.

dataset.dataset2struct

```
load('hospital')
```

Create a dataset array, D, that has only a subset of the observations and variables.

```
D = hospital(1:8,{'LastName','Sex','Age'});  
size(D)
```

```
ans =
```

```
      8      3
```

The dataset array D has 8 observations and 3 variables.

Convert D to a scalar structure array.

```
S = dataset2struct(D,'AsScalar',true)
```

```
S =
```

```
ObsNames: {8x1 cell}  
LastName: {8x1 cell}  
      Sex: [8x1 nominal]  
      Age: [8x1 double]
```

The data in the fields of the scalar structure is 8x1, corresponding to the 8 observations in the dataset array. S also has the field `ObsNames`, since D had observation names.

Display the data for the field `LastName`.

```
S.LastName
```

```
ans =
```

```
'SMITH'  
'JOHNSON'  
'WILLIAMS'  
'JONES'
```

```
'BROWN'  
'DAVIS'  
'MILLER'  
'WILSON'
```

The structure field `LastName` contains all of the data that was in the original dataset array variable, `LastName`.

See Also

[dataset](#) | [dataset2cell](#) | [struct2dataset](#)

Concepts

- “Dataset Arrays” on page 2-156

dataset.datasetfun

Purpose Apply function to dataset array variables

Syntax

```
b = datasetfun(fun,A)
[b,c,...] = datasetfun(fun,A)
[b,...] = datasetfun(fun,A,...,'UniformOutput',false)
[b,...] = datasetfun(fun,A,...,'DatasetOutput',true)
[b,...] = datasetfun(fun,A,...,'DataVars',vars)
[b,...] = datasetfun(fun,A,...,'ObsNames',obsnames)
[b,...] = datasetfun(fun,A,...,'ErrorHandler',efun)
```

Description `b = datasetfun(fun,A)` applies the function specified by `fun` to each variable of the dataset array `A`, and returns the results in the vector `b`. The i th element of `b` is equal to `fun` applied to the i th dataset variable of `A`. `fun` is a function handle to a function that takes one input argument and returns a scalar value. `fun` must return values of the same class each time it is called, and `datasetfun` concatenates them into the vector `b`. The outputs from `fun` must be one of the following types: numeric, logical, character, structure, or cell.

To apply functions that return results that are nonscalar or of different sizes and types, use the `'UniformOutput'` or `'DatasetOutput'` parameters described below.

Do not rely on the order in which `datasetfun` computes the elements of `b`, which is unspecified.

If `fun` is bound to more than one built-in function or file, (that is, if it represents a set of overloaded functions), `datasetfun` follows MATLAB dispatching rules in calling the function. (See “Function Precedence Order”.)

`[b,c,...] = datasetfun(fun,A)`, where `fun` is a function handle to a function that returns multiple outputs, returns vectors `b`, `c`, ..., each corresponding to one of the output arguments of `fun`. `datasetfun` calls `fun` each time with as many outputs as there are in the call to `datasetfun`. `fun` may return output arguments having different classes, but the class of each output must be the same each time `fun` is called.

`[b,...] = datasetfun(fun,A,...,'UniformOutput',false)` allows you to specify a function `fun` that returns values of different sizes or types. `datasetfun` returns a cell array (or multiple cell arrays), where the *i*th cell contains the value of `fun` applied to the *i*th dataset variable of `A`. Setting `'UniformOutput'` to `true` is equivalent to the default behavior.

`[b,...] = datasetfun(fun,A,...,'DatasetOutput',true)` specifies that the output(s) of `fun` are returned as variables in a dataset array (or multiple dataset arrays). `fun` must return values with the same number of rows each time it is called, but it may return values of any type. The variables in the output dataset array(s) have the same names as the variables in the input. Setting `'DatasetOutput'` to `false` (the default) specifies that the type of the output(s) from `datasetfun` is determined by `'UniformOutput'`.

`[b,...] = datasetfun(fun,A,...,'DataVars',vars)` allows you to apply `fun` only to the dataset variables in `A` specified by `vars`. `vars` is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector.

`[b,...] = datasetfun(fun,A,...,'ObsNames',obsnames)` specifies observation names for the dataset output when `'DatasetOutput'` is `true`.

`[b,...] = datasetfun(fun,A,...,'ErrorHandler',efun)`, where `efun` is a function handle, specifies the MATLAB function to call if the call to `fun` fails. The error-handling function is called with the following input arguments:

- A structure with the fields `identifier`, `message`, and `index`, respectively containing the identifier of the error that occurred, the text of the error message, and the linear index into the input array(s) at which the error occurred
- The set of input arguments at which the call to the function failed

The error-handling function should either re-throw an error, or return the same number of outputs as `fun`. These outputs are then returned as

dataset.datasetfun

the outputs of `datasetfun`. If `'UniformOutput'` is true, the outputs of the error handler must also be scalars of the same type as the outputs of `fun`. For example, the following code could be saved in a file as the error-handling function:

```
function [A,B] = errorFunc(S,varargin)

warning(S.identifier,S.message);
A = NaN;
B = NaN;
```

If an error-handling function is not specified, the error from the call to `fun` is rethrown.

Examples

Compute statistics on selected variables in the `hospital` dataset array:

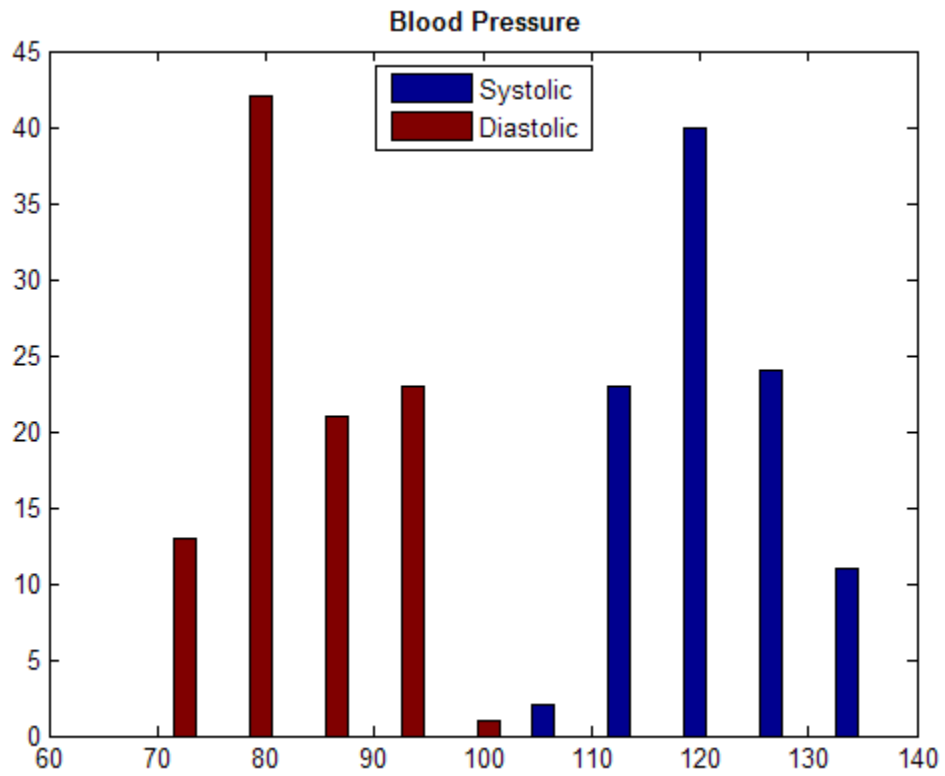
```
load hospital

stats = ...
    datasetfun(@mean,hospital,...
               'DataVars',{'Weight','BloodPressure'},...
               'UniformOutput',false)

stats =
    [154]    [1x2 double]
stats{2}
ans =
    122.7800    82.9600
```

Display the blood pressure variable:

```
datasetfun(@hist,hospital,...
           'DataVars','BloodPressure',...
           'UniformOutput',false);
title('{\bf Blood Pressure}')
legend('Systolic','Diastolic','Location','N')
```



See Also `grpstats`

daugment

Purpose *D*-optimal augmentation

Syntax
`dCE2 = daugment(dCE, mruns)`
`[dCE2, X] = daugment(dCE, mruns)`
`[dCE2, X] = daugment(dCE, mruns, model)`
`[dCE2, X] = daugment(..., param1, val1, param2, val2, ...)`

Description `dCE2 = daugment(dCE, mruns)` uses a coordinate-exchange algorithm to *D*-optimally add `mruns` runs to an existing experimental design `dCE` for a linear additive model.

`[dCE2, X] = daugment(dCE, mruns)` also returns the design matrix `X` associated with the augmented design.

`[dCE2, X] = daugment(dCE, mruns, model)` uses the linear regression model specified in `model`. `model` is one of the following strings:

- 'linear' — Constant and linear terms. This is the default.
- 'interaction' — Constant, linear, and interaction terms
- 'quadratic' — Constant, linear, interaction, and squared terms
- 'purequadratic' — Constant, linear, and squared terms

The order of the columns of `X` for a full quadratic model with n terms is:

- 1 The constant term
- 2 The linear terms in order 1, 2, ..., n
- 3 The interaction terms in order (1, 2), (1, 3), ..., (1, n), (2, 3), ..., ($n-1$, n)
- 4 The squared terms in order 1, 2, ..., n

Other models use a subset of these terms, in the same order.

Alternatively, `model` can be a matrix specifying polynomial terms of arbitrary order. In this case, `model` should have one column for each factor and one row for each term in the model. The entries in any row of `model` are powers for the factors in the columns. For example, if a

model has factors X1, X2, and X3, then a row [0 1 2] in *model* specifies the term $(X1.^0) \cdot (X2.^1) \cdot (X3.^2)$. A row of all zeros in *model* specifies a constant term, which can be omitted.

[dCE2,X] = daugment(...,param1,val1,param2,val2,...) specifies additional parameter/value pairs for the design. Valid parameters and their values are listed in the following table.

Parameter	Value
'bounds'	Lower and upper bounds for each factor, specified as a 2-by-nfactors matrix, where nfactors is the number of factors. Alternatively, this value can be a cell array containing nfactors elements, each element specifying the vector of allowable values for the corresponding factor.
'categorical'	Indices of categorical predictors.
'display'	Either 'on' or 'off' to control display of the iteration counter. The default is 'on'.
'excldefun'	Handle to a function that excludes undesirable runs. If the function is <i>f</i> , it must support the syntax $b = f(S)$, where <i>S</i> is a matrix of treatments with nfactors columns, where nfactors is the number of factors, and <i>b</i> is a vector of Boolean values with the same number of rows as <i>S</i> . <i>b</i> (<i>i</i>) is true if the <i>i</i> th row <i>S</i> should be excluded.
'init'	Initial design as an mruns-by-nfactors matrix, where nfactors is the number of factors. The default is a randomly selected set of points.
'levels'	Vector of number of levels for each factor.
'maxiter'	Maximum number of iterations. The default is 10.

Parameter	Value
'options'	<p>The value is a structure that contains options specifying whether to compute multiple tries in parallel, and specifying how to use random numbers when generating the starting points for the tries. Create the options structure with <code>statset</code>. Applicable <code>statset</code> parameters are:</p> <ul style="list-style-type: none"> • <code>'UseParallel'</code> — If <code>'always'</code> and if a <code>matlabpool</code> of the Parallel Computing Toolbox is open, compute in parallel. If the Parallel Computing Toolbox is not installed, or a <code>matlabpool</code> is not open, computation occurs in serial mode. Default is <code>'never'</code>, meaning serial computation. • <code>UseSubstreams</code> — Set to <code>'always'</code> to compute in parallel in a reproducible fashion. Default is <code>'never'</code>. To compute reproducibly, set <code>Streams</code> to a type allowing substreams: <code>'mlfg6331_64'</code> or <code>'mrg32k3a'</code>. • <code>Streams</code> — A <code>RandStream</code> object or cell array of such objects. If you do not specify <code>Streams</code>, <code>daugment</code> uses the default stream or streams. If you choose to specify <code>Streams</code>, use a single object except in the case <ul style="list-style-type: none"> ▪ You have an open MATLAB pool ▪ <code>UseParallel</code> is <code>'always'</code> ▪ <code>UseSubstreams</code> is <code>'never'</code> In that case, use a cell array the same size as the MATLAB pool.
'tries'	<p>Number of times to try to generate a design from a new starting point. The algorithm uses random points for each try, except possibly the first. The default is 1.</p>

Note The `daugment` function augments an existing design using a coordinate-exchange algorithm; the `'start'` parameter of the `candexch` function provides the same functionality using a row-exchange algorithm.

Examples

The following eight-run design is adequate for estimating main effects in a four-factor model:

```
dCEmain = candexch(4,8)
dCEmain =
     1    -1    -1     1
    -1    -1     1     1
    -1     1    -1     1
     1     1     1    -1
     1     1     1     1
    -1     1    -1    -1
     1    -1    -1    -1
    -1    -1     1    -1
```

To estimate the six interaction terms in the model, augment the design with eight additional runs:

```
dCEinteraction = daugment(dCEmain,8,'interaction')
dCEinteraction =
     1    -1    -1     1
    -1    -1     1     1
    -1     1    -1     1
     1     1     1    -1
     1     1     1     1
    -1     1    -1    -1
     1    -1    -1    -1
    -1    -1     1    -1
    -1     1     1     1
    -1    -1    -1    -1
     1    -1     1    -1
```

daugment

1	1	-1	1
-1	1	1	-1
1	1	-1	-1
1	-1	1	1
1	1	1	-1

The augmented design is full factorial, with the original eight runs in the first eight rows.

See Also

[dcovary](#) | [cordexch](#) | [candexch](#)

Purpose

D-optimal design with fixed covariates

Syntax

```
dCV = dcovary(nfactors, fixed)
[dCV, X] = dcovary(nfactors, fixed)
[dCV, X] = dcovary(nfactors, fixed, model)
[dCV, X] = daugment(..., param1, val1, param2, val2, ...)
```

Description

`dCV = dcovary(nfactors, fixed)` uses a coordinate-exchange algorithm to generate a *D*-optimal design for a linear additive model with `nfactors` factors, subject to the constraint that the model include the fixed covariate factors in `fixed`. The number of runs in the design is the number of rows in `fixed`. The design `dCV` augments `fixed` with initial columns for treatments of the model terms.

`[dCV, X] = dcovary(nfactors, fixed)` also returns the design matrix `X` associated with the design.

`[dCV, X] = dcovary(nfactors, fixed, model)` uses the linear regression model specified in `model`. `model` is one of the following strings:

- 'linear' — Constant and linear terms. This is the default.
- 'interaction' — Constant, linear, and interaction terms
- 'quadratic' — Constant, linear, interaction, and squared terms
- 'purequadratic' — Constant, linear, and squared terms

The order of the columns of `X` for a full quadratic model with n terms is:

- 1** The constant term
- 2** The linear terms in order 1, 2, ..., n
- 3** The interaction terms in order (1, 2), (1, 3), ..., (1, n), (2, 3), ..., ($n-1$, n)
- 4** The squared terms in order 1, 2, ..., n

Other models use a subset of these terms, in the same order.

Alternatively, *model* can be a matrix specifying polynomial terms of arbitrary order. In this case, *model* should have one column for each factor and one row for each term in the model. The entries in any row of *model* are powers for the factors in the columns. For example, if a model has factors X1, X2, and X3, then a row [0 1 2] in *model* specifies the term $(X1.^0) \cdot (X2.^1) \cdot (X3.^2)$. A row of all zeros in *model* specifies a constant term, which can be omitted.

[dCV,X] = daugment(...,param1,val1,param2,val2,...) specifies additional parameter/value pairs for the design. Valid parameters and their values are listed in the following table.

Parameter	Value
'bounds'	Lower and upper bounds for each factor, specified as a 2-by-nfactors matrix. Alternatively, this value can be a cell array containing nfactors elements, each element specifying the vector of allowable values for the corresponding factor.
'categorical'	Indices of categorical predictors.
'display'	Either 'on' or 'off' to control display of the iteration counter. The default is 'on'.
'excludefun'	Handle to a function that excludes undesirable runs. If the function is <i>f</i> , it must support the syntax $b = f(S)$, where <i>S</i> is a matrix of treatments with nfactors columns and <i>b</i> is a vector of Boolean values with the same number of rows as <i>S</i> . <i>b</i> (<i>i</i>) is true if the <i>i</i> th row <i>S</i> should be excluded.
'init'	Initial design as an mruns-by-nfactors matrix. The default is a randomly selected set of points.
'levels'	Vector of number of levels for each factor.
'maxiter'	Maximum number of iterations. The default is 10.

Parameter	Value
'options'	<p>The value is a structure that contains options specifying whether to compute multiple tries in parallel, and specifying how to use random numbers when generating the starting points for the tries. Create the options structure with <code>statset</code>. Applicable <code>statset</code> parameters are:</p> <ul style="list-style-type: none"> • 'UseParallel' — If 'always' and if a <code>matlabpool</code> of the Parallel Computing Toolbox is open, compute in parallel. If the Parallel Computing Toolbox is not installed, or a <code>matlabpool</code> is not open, computation occurs in serial mode. Default is 'never', meaning serial computation. • <code>UseSubstreams</code> — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set <code>Streams</code> to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'. • <code>Streams</code> — A <code>RandStream</code> object or cell array of such objects. If you do not specify <code>Streams</code>, <code>dcovary</code> uses the default stream or streams. If you choose to specify <code>Streams</code>, use a single object except in the case <ul style="list-style-type: none"> ▪ You have an open MATLAB pool ▪ <code>UseParallel</code> is 'always' ▪ <code>UseSubstreams</code> is 'never' In that case, use a cell array the same size as the MATLAB pool.
'tries'	<p>Number of times to try to generate a design from a new starting point. The algorithm uses random points for each try, except possibly the first. The default is 1.</p>

Examples

Example 1

Suppose you want a design to estimate the parameters in a three-factor linear additive model, with eight runs that necessarily occur at different times. If the process experiences temporal linear drift, you may want to include the run time as a variable in the model. Produce the design as follows:

```
time = linspace(-1,1,8)';
[dCV1,X] = dcovary(3,time,'linear')
dCV1 =
    -1.0000     1.0000     1.0000    -1.0000
     1.0000    -1.0000    -1.0000    -0.7143
    -1.0000    -1.0000    -1.0000    -0.4286
     1.0000    -1.0000     1.0000    -0.1429
     1.0000     1.0000    -1.0000     0.1429
    -1.0000     1.0000    -1.0000     0.4286
     1.0000     1.0000     1.0000     0.7143
    -1.0000    -1.0000     1.0000     1.0000
X =
     1.0000    -1.0000     1.0000     1.0000    -1.0000
     1.0000     1.0000    -1.0000    -1.0000    -0.7143
     1.0000    -1.0000    -1.0000    -1.0000    -0.4286
     1.0000     1.0000    -1.0000     1.0000    -0.1429
     1.0000     1.0000     1.0000    -1.0000     0.1429
     1.0000    -1.0000     1.0000    -1.0000     0.4286
     1.0000     1.0000     1.0000     1.0000     0.7143
     1.0000    -1.0000    -1.0000     1.0000     1.0000
```

The column vector `time` is a fixed factor, normalized to values between ± 1 . The number of rows in the fixed factor specifies the number of runs in the design. The resulting design `dCV` gives factor settings for the three controlled model factors at each time.

Example 2

The following example uses the `dummyvar` function to block an eight-run experiment into 4 blocks of size 2 for estimating a linear additive model with two factors:

```
fixed = dummyvar([1 1 2 2 3 3 4 4]);
dCV2 = dcovary(2, fixed(:, 1:3), 'linear')
dCV2 =
    1    1    1    0    0
   -1   -1    1    0    0
   -1    1    0    1    0
    1   -1    0    1    0
    1    1    0    0    1
   -1   -1    0    0    1
   -1    1    0    0    0
    1   -1    0    0    0
```

The first two columns of dCV2 contain the settings for the two factors; the last three columns are dummy variable codings for the four blocks.

See Also

[daugment](#) | [cordexch](#) | [dummyvar](#)

TreeBagger.DefaultYfit property

Purpose Default value returned by `predict` and `oobPredict`

Description The `DefaultYfit` property controls what predicted value `TreeBagger` returns when no prediction is possible, for example when the `oobPredict` method needs to predict for an observation that is in-bag for all trees in the ensemble.

For classification, you can set this property to either `' '` or `'MostPopular'`. If you choose `'MostPopular'` (default), the property value becomes the name of the most probable class in the training data.

For regression, you can set this property to any numeric scalar. The default is the mean of the response for the training data.

If you set this property to `' '` for classification or `NaN` for regression, `TreeBagger` excludes the in-bag observations from computation of the out-of-bag error and margin.

See Also `oobPredict` | `Predict` | `OOBIndices`

Purpose Delete handle object

Syntax `delete(h)`

Description `delete(h)` deletes the handle object `h`, where `h` is a scalar handle. The `delete` method deletes a handle object but does not clear the handle from the workspace. A deleted handle is no longer valid.

See Also `clear` | `isvalid` | `grandstream`

TreeBagger.DeltaCritDecisionSplit property

- Purpose** Split criterion contributions for each predictor
- Description** The `DeltaCritDecisionSplit` property is a numeric array of size 1-by-Nvars of changes in the split criterion summed over splits on each variable, averaged across the entire ensemble of grown trees.
- See Also** `classregtree.varimportance`

Purpose

Dendrogram plot

Syntax

```
dendrogram(tree)
dendrogram(tree,Name,Value)
```

```
dendrogram(tree,P)
dendrogram(tree,P,Name,Value)
```

```
H = dendrogram( ___ )
[H,T,outperm] = dendrogram( ___ )
```

Description

`dendrogram(tree)` generates a dendrogram plot of the hierarchical binary cluster tree. A dendrogram consists of many *U*-shaped lines that connect data points in a hierarchical tree. The height of each *U* represents the distance between the two data points being connected.

- If there are 30 or fewer data points in the original data set, then each leaf in the dendrogram corresponds to one data point.
- If there are more than 30 data points, then `dendrogram` collapses lower branches so that there are 30 leaf nodes. As a result, some leaves in the plot correspond to more than one data point.

`dendrogram(tree,Name,Value)` uses additional options specified by one or more name-value pair arguments.

`dendrogram(tree,P)` generates a dendrogram plot with no more than *P* leaf nodes. If there are more than *P* data points in the original data set, then `dendrogram` collapses the lower branches of the tree. As a result, some leaves in the plot correspond to more than one data point.

`dendrogram(tree,P,Name,Value)` uses additional options specified by one or more name-value pair arguments.

dendrogram

`H = dendrogram(___)` generates a dendrogram plot and returns a vector of line handles. You can use any of the input arguments from the previous syntaxes.

`[H,T,outperm] = dendrogram(___)` also returns a vector containing the leaf node number for each object in the original data set, `T`, and a vector giving the order of the node labels of the leaves as shown in the dendrogram, `outperm`.

- It is useful to return `T` when the number of leaf nodes, `P`, is less than the total number of data points, so that some leaf nodes in the display correspond to multiple data points.
- The order of the node labels given in `outperm` is from left to right for a horizontal dendrogram, and from bottom to top for a vertical dendrogram.

Input Arguments

tree - Hierarchical binary cluster tree

matrix returned by `linkage`

Hierarchical binary cluster tree, specified as an $(M - 1)$ -by-3 matrix that you generate using `linkage`, where M is the number of data points in the original data set.

P - Maximum number of leaf nodes

30 (default) | positive integer value

Maximum number of leaf nodes to include in the dendrogram plot, specified as a positive integer value.

- If there are `P` or fewer data points in the original data set, then each leaf in the dendrogram corresponds to one data point.
- If there are more than `P` data points, then `dendrogram` collapses lower branches so that there are `P` leaf nodes. As a result, some leaves in the plot correspond to more than one data point.

If you do not specify `P`, then `dendrogram` uses 30 as the maximum number of leaf nodes. To display the complete tree, set `P` equal to 0.

Data Types

single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Orientation','left','Reorder',myOrder`, specifies a vertical dendrogram with leaves in the order specified by `myOrder`.

Reorder - Order of leaf nodes

vector

Order of leaf nodes in the dendrogram plot, specified as the comma-separated pair consisting of `'Reorder'` and a vector giving the order of nodes in the complete tree. The order vector must be a permutation of the vector `1:M`, where M is the number of data points in the original data set. Specify the order from left to right for horizontal dendrograms, and from bottom to top for vertical dendrograms.

If M is greater than the number of leaf nodes in the dendrogram plot, P (by default, P is 30), then you can only specify a permutation vector that does not separate the groups of leaves that correspond to collapsed nodes.

Example:

Data Types

single | double

CheckCrossing - Indicator for whether to check for crossing branches

true (default) | false

Indicator for whether to check for crossing branches in the dendrogram plot, specified as the comma-separated pair consisting of

dendrogram

'CheckCrossing' and either true or false. This option is only useful when you specify a value for Reorder.

When CheckCrossing has the value true, dendrogram issues a warning if the order of the leaf nodes causes crossing branches in the plot. If the dendrogram plot does not show a complete tree (because the number of data points in the original data set is greater than P), dendrogram only issues a warning when the order of the leaf nodes causes branch to cross in the dendrogram as shown in the plot. That is, there is no warning if the order causes crossing branches in the complete tree but not in the dendrogram as shown in the plot.

Data Types

logical

ColorThreshold - Threshold for unique colors

'default' | scalar value in the range (0,max(tree(:,3)))

Threshold for unique colors in the dendrogram plot, specified as the comma-separated pair consisting of 'ColorThreshold' and either the string 'default' or a scalar value in the range (0,max(tree(:,3))). If ColorThreshold has the value T , then dendrogram assigns a unique color to each group of nodes in the dendrogram whose linkage is less than T .

- If ColorThreshold has the value 'default', then the threshold, T , is 70% of the maximum linkage, $0.7*\max(\text{tree}(:,3))$.
- If you do not specify a value for ColorThreshold, or if you specify a threshold outside the range (0,max(tree(:,3))), then dendrogram uses only one color for the dendrogram plot.

Orientation - Orientation of dendrogram

'top' (default) | 'bottom' | 'left' | 'right'

Orientation of the dendrogram in the figure window, specified as the comma-separated pair consisting of 'Orientation' and one of these strings:

'top'	Top to bottom
'bottom'	Bottom to top
'left'	Left to right
'right'	Right to left

Data Types

char

Labels - Label for each data point

character array | cell array of strings

Label for each data point in the original data set, specified as the comma-separated pair consisting of 'Labels' and a character array or cell array of strings. `dendrogram` labels any leaves in the dendrogram plot containing a single data point with that data point's label.

Data Types

char | cell

Output Arguments

H - Handles to lines

vector

Handles to lines in the dendrogram plot, returned as a vector.

T - Leaf node numbers

column vector

Leaf node numbers for each data point in the original data set, returned as a column vector of length M , where M is the number of data points in the original data set.

When there are fewer than P data points in the original data (P is 30, by default), all data points are displayed in the dendrogram, with each node containing a single data point. In this case, T is the identity map, $T = (1:M)'$.

T is useful when P is less than the total number of data points. That is, when some leaf nodes in the dendrogram display correspond to multiple

dendrogram

data points. For example, to find out which data points are contained in leaf node k of the dendrogram plot, use `find(T==k)`.

outperm - Permutation of node labels

vector

Permutation of the node labels of the leaves of the dendrogram as shown in the plot, returned as a row vector. `outperm` gives the order from left to right for a horizontal dendrogram, and from bottom to top for a vertical dendrogram. If there are P leaves in the dendrogram plot, `outperm` is a permutation of the vector $1:P$.

Examples

Plot Dendrogram

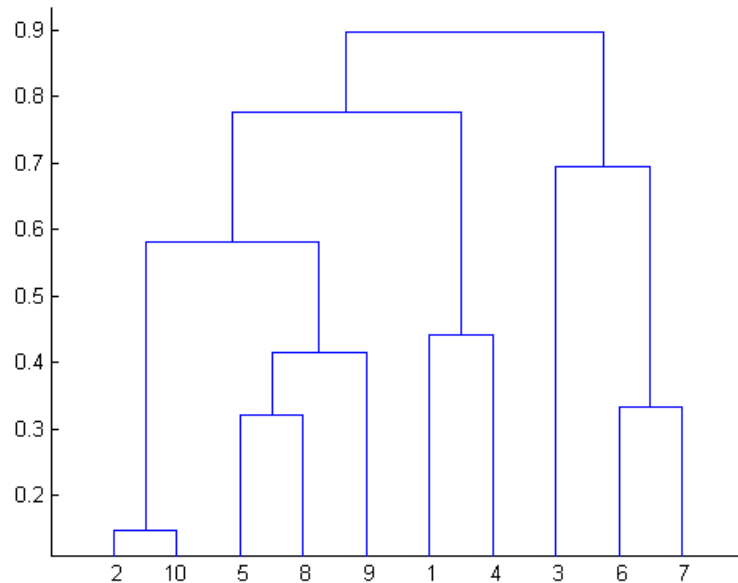
Generate sample data.

```
rng('default') % For reproducibility
X = rand(10,3);
```

Create a hierarchical binary cluster tree using `linkage`. Then, plot the dendrogram using the default options.

```
tree = linkage(X,'average');

figure()
dendrogram(tree)
```



Specify Dendrogram Leaf Node Order

Generate sample data.

```
rng('default') % For reproducibility  
X = rand(10,3);
```

Create a hierarchical binary cluster tree using `linkage`. Then, plot the dendrogram using an optimal leaf order.

```
tree = linkage(X,'average');
```

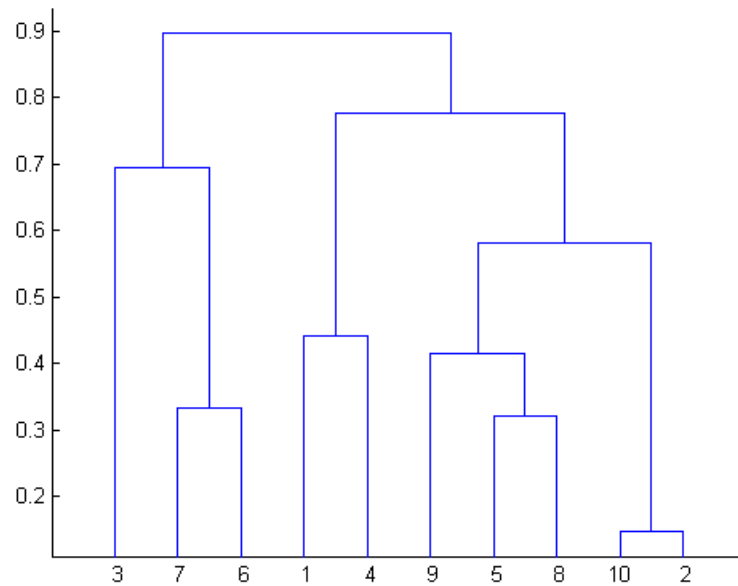
```
D = pdist(X);  
leafOrder = optimalleaforder(tree,D)
```

```
leafOrder =
```

dendrogram

3 7 6 1 4 9 5 8 10 2

```
figure()  
dendrogram(tree,'Reorder',leafOrder)
```



The order of the leaf nodes in the dendrogram plot corresponds—from left to right—to the permutation in `leafOrder`.

Specify Number of Nodes in Dendrogram Plot

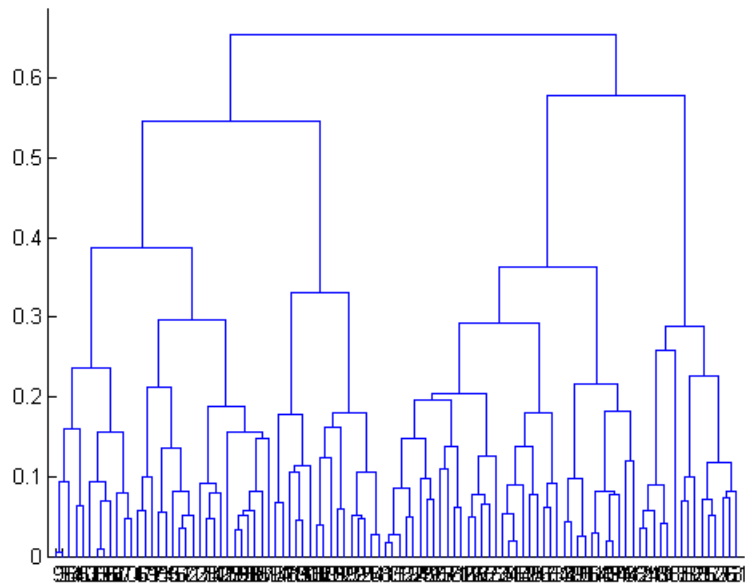
Generate sample data.

```
rng('default') % For reproducibility  
X = rand(100,2);
```

There are 100 data points in the original data set, `X`.

Create a hierarchical binary cluster tree using `linkage`. Then, plot the dendrogram for the complete tree (100 leaf nodes) by setting the input argument `P` equal to 0.

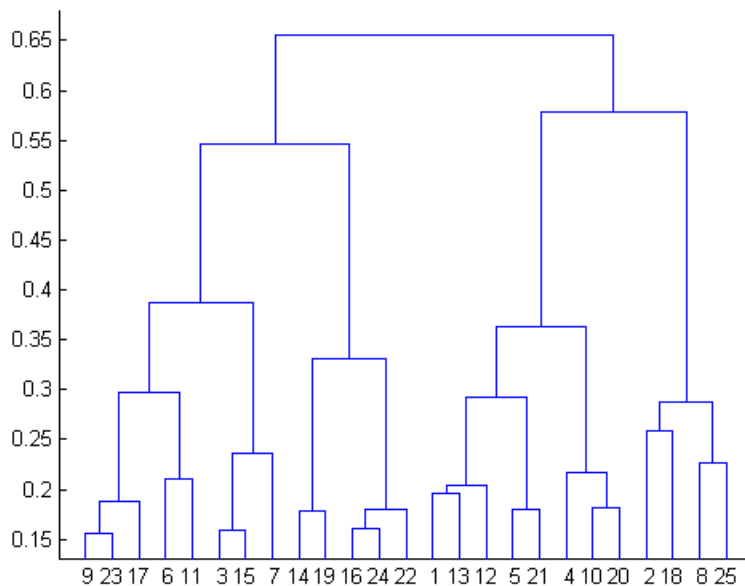
```
tree = linkage(X,'average');  
  
figure()  
dendrogram(tree,0)
```



Now, plot the dendrogram with only 25 leaf nodes. Return the mapping of the original data points to the leaf nodes shown in the plot.

```
figure()  
[~,T] = dendrogram(tree,25);
```

dendrogram



List the original data points that are in leaf node 7 of the dendrogram plot.

```
find(T==7)
```

```
ans =
```

```
7  
33  
60  
70  
74  
76  
86
```

Change Dendrogram Orientation and Line Width

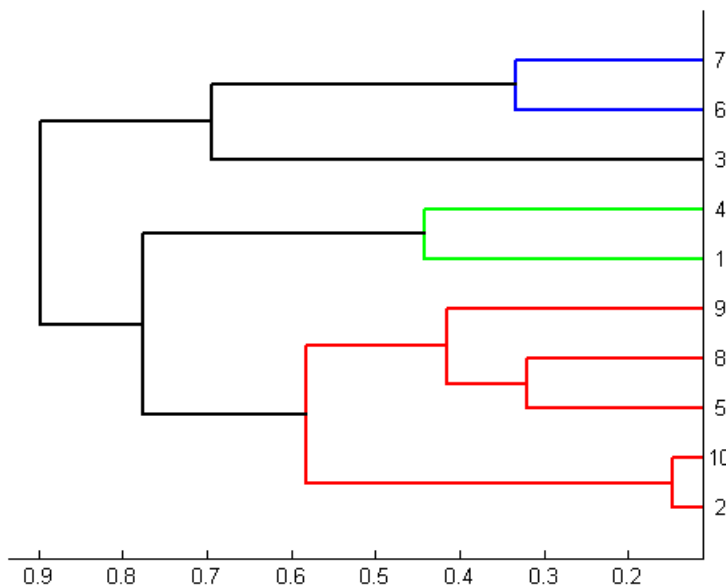
Generate sample data.

```
rng('default') % For reproducibility  
X = rand(10,3);
```

Create a hierarchical binary cluster tree using `linkage`. Then, plot the dendrogram with a vertical orientation, using the default color threshold. Return handles to the lines so you can change the dendrogram line widths.

```
tree = linkage(X,'average');  
  
figure()  
H = dendrogram(tree,'Orientation','left','ColorThreshold','default');  
set(H,'LineWidth',2)
```

dendrogram



See Also

`cluster` | `clusterdata` | `cophenet` | `inconsistent` | `linkage` |
`pdist` | `silhouette`

dataset.Description property

Purpose String describing data set

Description Description is a string describing the data set. The default is an empty string.

GeneralizedLinearModel.devianceTest

Purpose	Analysis of deviance
Syntax	<code>tbl = devianceTest mdl</code>
Description	<code>tbl = devianceTest mdl</code> returns an analysis of deviance table for the <code>mdl</code> generalized linear model. <code>tbl</code> gives the result of a test of whether the fitted model fits significantly better than a constant model.
Input Arguments	mdl Generalized linear model, as constructed by <code>GeneralizedLinearModel.fit</code> or <code>GeneralizedLinearModel.stepwise</code> .
Output Arguments	tbl Dataset array containing two rows and four columns. <ul style="list-style-type: none">• The first row relates to a constant model.• The second row relates to the full model in <code>mdl</code>.• The columns are (see “Definitions” on page 20-516):<ul style="list-style-type: none">▪ Deviance▪ DFE (Error Degrees of Freedom)▪ F statistic or Chi-squared statistic, depending on whether the dispersion is estimated (F statistic) or not (Chi-squared statistic)▪ p-value associated with the test

Definitions **Deviance Test Statistics for a Generalized Linear Model**

- *Deviance* is twice the difference between the log likelihoods of the models (full or constant).

- *DFE* is the number of observations minus the number of parameters in the model.
- *Chi-squared statistic* is the difference between the deviance of the constant model and the deviance of the full model.
- *F statistic* is the difference between the deviance of the constant model and the deviance of the full model, divided by the estimated dispersion.
- *p-value* is the Chi-squared statistic with (number of coefficients in the model minus one) degrees of freedom, or *F* statistic with (number of coefficients in the model minus one) numerator degrees of freedom, and DFE denominator degrees of freedom.

Examples

Deviance Test

Perform a deviance test on a generalized linear model.

Construct a generalized linear model.

```
rng('default') % for reproducibility
X = randn(100,5);
mu = exp(X(:, [1 4 5]) * [.4; .2; .3]);
y = poissrnd(mu);
mdl = GeneralizedLinearModel.fit(X,y,...
    'linear', 'Distribution', 'poisson');
```

Test whether the model differs from a constant in a statistically significant way.

```
tbl = devianceTest(mdl)
```

```
tbl =
```

	Deviance	DFE	chi2Stat	pValue
log(y) ~ 1	128.58	99		
log(y) ~ 1 + x1 + x2 + x3 + x4 + x5	83.726	94	44.858	1.5502e-08

GeneralizedLinearModel.devianceTest

The p -value is very small, indicating that the model significantly differs from a constant.

See Also `GeneralizedLinearModel` |

Concepts

- “Generalized Linear Models” on page 9-141

Purpose Interactive distribution fitting

Syntax

```
dfittool
dfittool(y)
dfittool(y,cens)
dfittool(y,cens,freq)
dfittool(y,cens,freq,dsname)
```

Description `dfittool` opens a graphical user interface for displaying fit distributions to data. To fit distributions to your data and display them over plots of the empirical distributions, you can import data from the workspace.

`dfittool(y)` displays the Distribution Fitting Tool and creates a data set with data specified by the vector `y`.

`dfittool(y,cens)` uses the vector `cens` to specify whether the observation `y(j)` is censored, (`cens(j)==1`) and/or observed, exactly (`cens(j)==0`). If `cens` is omitted or empty, no `y` values are censored.

`dfittool(y,cens,freq)` uses the vector `freq` to specify the frequency of each element of `y`. If `freq` is omitted or empty, all `y` values have a frequency of 1.

`dfittool(y,cens,freq,dsname)` creates a data set with the name `dsname` using the data vector `y`, censoring indicator `cens`, and frequency vector `freq`.

For more information, see “Modeling Data Using the Distribution Fitting Tool” on page 5-12.

See Also `mle` | `randtool` | `disttool`

grandset.Dimensions property

Purpose Number of dimensions

Description Number of dimensions in the point set. The `Dimensions` property of a point set contains a positive integer that indicates the number of dimensions for which the points have values. For example, a point set with `Dimensions=5` produces points that each have five values.

Set this property by specifying the number of dimensions when constructing a new point set. After construction, you cannot change the value. The default number of dimensions is 2.

dataset.DimNames property

Purpose

Two-element cell array of strings giving names of dimensions of data set

Description

A two-element cell array of strings giving the names of the two dimensions of the data set. The default is {'Observations' 'Variables'}.

categorical disp

Purpose	Display categorical array
Syntax	<code>disp(A)</code>
Description	<code>disp(A)</code> prints the categorical array <code>A</code> without printing the array name. In all other ways it's the same as leaving the semicolon off an expression, except that empty arrays don't display.
See Also	<code>categorical</code> <code>display</code>

Purpose Display classregtree object

Syntax `display(t)`

Description `display(t)` prints the classregtree object `t`.

See Also `classregtree` | `view`

cvpartition.disp

Purpose	Display cvpartition object
Syntax	<code>disp(c)</code>
Description	<code>disp(c)</code> prints the cvpartition object <code>c</code> .
See Also	<code>cvpartition</code>

Purpose Display dataset array

Syntax `disp(ds)`

Description `disp(ds)` prints the dataset array `ds`, including variable names and observation names (if present), without printing the dataset name. In all other ways it's the same as leaving the semicolon off an expression.

For numeric or categorical variables that are 2-D and have three or fewer columns, `disp` prints the actual data using either short `g`, long `g`, or bank format, depending on the current command line setting. Otherwise, `disp` prints the size and type of each dataset element.

For character variables that are 2-D and 10 or fewer characters wide, `disp` prints quoted strings. Otherwise, `disp` prints the size and type of each dataset element.

For cell variables that are 2-D and have three or fewer columns, `disp` prints the contents of each cell (or its size and type if too large). Otherwise, `disp` prints the size of each dataset element.

For time series variables, `disp` prints columns for both the time and the data. If the variable is 2-D and has three or fewer columns, `disp` prints the actual data. Otherwise, `disp` prints the size and type of each dataset element.

For other types of variables, `disp` prints the size and type of each dataset element.

See Also `dataset` | `display` | `format`

GeneralizedLinearModel.disp

Purpose Display generalized linear regression model

Syntax `disp mdl`

Description `disp mdl` displays the `mdl` linear model.

Input Arguments **mdl**
Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

Examples **Display a Generalized Linear Regression Model**

Create and display a generalized linear regression model.

Create a generalized linear regression model of Poisson data.

```
X = 2 + randn(100,1);  
mu = exp(1 + X/2);  
y = poissrnd(mu);  
mdl = GeneralizedLinearModel.fit(X,y,...  
    'y ~ x1','distr','poisson');
```

Display the model.

```
disp(mdl)
```

```
Generalized Linear regression model:
```

```
log(y) ~ 1 + x1  
Distribution = Poisson
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	0.9581	0.090294	10.611	2.6519e-26
x1	0.51027	0.033738	15.124	1.1179e-51


```
100 observations, 98 error degrees of freedom  
Dispersion: 1  
Chi^2-statistic vs. constant model: 221, p-value = 5.77e-50
```

Alternatives Enter *mdl* at the command line to obtain a display, where *mdl* is the name of your model.

See Also [GeneralizedLinearModel](#) |

Concepts

- “Generalized Linear Models” on page 9-141

gmdistribution.disp

Purpose	Display Gaussian mixture distribution object
Syntax	<code>disp(obj)</code>
Description	<code>disp(obj)</code> prints a text representation of the <code>gmdistribution</code> object, <code>obj</code> , without printing the object name. In all other ways it's the same as leaving the semicolon off an expression.
See Also	<code>gmdistribution</code> <code>display</code>

Purpose Display linear regression model

Syntax `display mdl`

Description `display mdl` displays the `mdl` linear model.

Input Arguments **mdl**
Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

Examples **Display a Linear Regression Model**

Create and display a linear regression model.

Create a linear regression model.

```
X = randn(100,5);  
y = X*[1;2;3;4;5] + 6 + randn(100,1);  
mdl = LinearModel.fit(X,y);
```

Display the model.

```
disp(mdl)
```

Linear regression model:

```
y ~ 1 + x1 + x2 + x3 + x4 + x5
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	6.0806	0.11393	53.371	4.2509e-72
x1	1.1181	0.1154	9.6894	8.4046e-16
x2	2.0903	0.11378	18.372	7.2209e-33
x3	3.0926	0.10725	28.836	1.7967e-48
x4	3.9343	0.11489	34.244	6.9609e-55
x5	4.9538	0.10799	45.873	3.8195e-66

LinearModel.disp

Number of observations: 100, Error degrees of freedom: 94
Root Mean Squared Error: 1.08
R-squared: 0.979, Adjusted R-Squared 0.978
F-statistic vs. constant model: 891, p-value = 1.59e-77

Alternatives

Enter *mdl* at the command line to obtain a display, where *mdl* is the name of your model.

See Also

LinearModel

How To

- “Linear Regression” on page 9-7
- “Stepwise Regression” on page 9-108
- “Robust Regression — Reduce Outlier Effects” on page 9-113

Purpose	Display NaiveBayes classifier object
Syntax	<code>disp(nb)</code>
Description	<code>disp(nb)</code> prints a text representation of the NaiveBayes object <code>nb</code> , without printing the object name. In all other ways it's the same as leaving the semicolon off an expression.
See Also	<code>NaiveBayes</code> <code>display</code>

NonLinearModel.disp

Purpose Display nonlinear regression model

Syntax `disp(md1)`

Description `disp(md1)` displays the `md1` nonlinear model at the command line.

Input Arguments **mdl**
Nonlinear regression model, constructed by `NonLinearModel.fit`.

Examples **Display a Nonlinear Regression Model**

Create and display a nonlinear regression model.

Load the reaction data, and specify both a model function and starting values for the iterations.

```
load reaction
modelfun = 'rate~(b1*x2-x3/b5)/(1+b2*x1+b3*x2+b4*x3)';
beta0 = [1 .05 .02 .1 2];
```

Create a model of the data.

```
mdl = NonLinearModel.fit(reactants,rate,...
    modelfun,beta0);
```

Display the model.

```
disp(md1)
```

```
Nonlinear regression model:
    rate ~ (b1*x2 - x3/b5)/(1 + b2*x1 + b3*x2 + b4*x3)
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
b1	1.2526	0.86701	1.4447	0.18654
b2	0.062776	0.043561	1.4411	0.18753
b3	0.040048	0.030885	1.2967	0.23089
b4	0.11242	0.075157	1.4957	0.17309

b5 1.1914 0.83671 1.4239 0.1923

Number of observations: 13, Error degrees of freedom: 8
Root Mean Squared Error: 0.193
R-Squared: 0.999, Adjusted R-Squared 0.998
F-statistic vs. constant model: 1.81e+03, p-value = 7.36e-12

Alternatives Enter *mdl* at the command line to obtain a display, where *mdl* is the name of your model.

See Also NonLinearModel |

Concepts • “Nonlinear Regression” on page 9-196

piecwisedistribution.disp

Purpose	Display piecwisedistribution object
Syntax	<code>disp(A)</code>
Description	<code>disp(A)</code> prints a text representation of the piecwisedistribution object A, without printing the object name. In all other ways it's the same as leaving the semicolon off an expression.
See Also	<code>piecwisedistribution</code>

Purpose Display grandset object

Syntax `disp(p)`

Description `disp(p)` displays the properties of the quasi-random point set `s`, without printing the variable name. `disp` prints out the number of dimensions and points in the point-set, and follows this with the list of all property values for the object.

See Also `grandset`

grandstream.disp

Purpose Display grandstream object

Syntax `disp(q)`

Description `disp(q)` displays the quasi-random stream `q`, without printing the variable name. `disp` prints the type and number of dimensions in the stream, and follows it with the list of point set properties.

See Also `grandstream`

Purpose Display categorical array

Syntax `display(A)`

Description `display(A)` prints the categorical array `A`. `categorical` calls `display` when a you do not use a semicolon to terminate a statement.

See Also `categorical` | `disp`

classregtree.display

Purpose	Display classregtree object
Syntax	<code>display(t)</code> <code>display(A)</code>
Description	<p><code>display(t)</code> prints the classregtree object <code>t</code>. <code>classregtree</code> calls <code>display</code> when a you do not use a semicolon to terminate a statement.</p> <p><code>display(A)</code> prints the categorical array <code>A</code>. <code>categorical</code> calls <code>display</code> when a you do not use a semicolon to terminate a statement.</p>
See Also	<code>classregtree</code> <code>eval</code> <code>prune</code> <code>test</code>

Purpose Display cvpartition object

Syntax `display(c)`

Description `display(c)` prints the cvpartition object `c`. `cvpartition` calls `display` when a you do not use a semicolon to terminate a statement.

See Also `cvpartition`

dataset.display

Purpose Display dataset array

Syntax `display(ds)`

Description `display(ds)` prints the dataset array `ds`, including variable names and observation names (if present). `dataset` calls `display` when a you do not use a semicolon to terminate a statement

For numeric or categorical variables that are 2-D and have three or fewer columns, `display` prints the actual data. Otherwise, `display` prints the size and type of each dataset element.

For character variables that are 2-D and 10 or fewer characters wide, `display` prints quoted strings. Otherwise, `display` prints the size and type of each dataset element.

For cell variables that are 2-D and have three or fewer columns, `display` prints the contents of each cell (or its size and type if too large). Otherwise, `display` prints the size of each dataset element.

For time series variables, `display` prints columns for both the time and the data. If the variable is 2-D and has three or fewer columns, `display` prints the actual data. Otherwise, `display` prints the size and type of each dataset element.

For other types of variables, `display` prints the size and type of each dataset element.

See Also `dataset` | `display` | `format`

Purpose Display Gaussian mixture distribution object

Syntax `display(obj)`

Description `display(obj)` prints a text representation of the `gmdistribution` object `obj`. `gmdistribution` calls `display` when a you do not use a semicolon to terminate a statement.

See Also `gmdistribution` | `disp`

NaiveBayes.display

Purpose Display NaiveBayes classifier object

Syntax `display(nb)`

Description `display(nb)` prints a text representation of the NaiveBayes object `nb`. NaiveBayes calls `display` when a you do not use a semicolon to terminate a statement.

See Also NaiveBayes | display

Purpose Display piecewisedistribution object

Syntax `display(A)`

Description `display(A)` prints a text representation of the piecewisedistribution object `A`, without printing the object name. `piecewisedistribution` calls `display` when a you do not use a semicolon to terminate a statement.

See Also `piecewisedistribution`

ProbDist.DistName property

Purpose Read-only string containing probability distribution name of ProbDist object

Description DistName is a read-only property of the ProbDist class. DistName is a string containing the type of distribution used to create the object.

Values Possible values are:

- 'kernel'
- 'beta'
- 'binomial'
- 'birnbaumsaunders'
- 'exponential'
- 'extreme value'
- 'gamma'
- 'generalized extreme value'
- 'generalized pareto'
- 'inversegaussian'
- 'logistic'
- 'loglogistic'
- 'lognormal'
- 'nakagami'
- 'negative binomial'
- 'normal'
- 'poisson'
- 'rayleigh'
- 'rician'

ProbDist.DistName property

- 'tlocationscale'
- 'weibull'

Use this information to view and compare the type of distribution used to create distribution objects.

NaiveBayes.Dist property

Purpose Distribution names

Description The `Dist` property is a string or a 1-by-NDims cell array of strings indicating the types of distributions for all the features. If all the features use the same type of distribution, `Dist` is a single string. Otherwise `Dist(j)` indicates the distribution type used for the `j`th feature.

The valid strings for this property are the following:

'normal'	Normal distribution.
'kernel'	Kernel smoothing density estimate.
'mvmn'	Multivariate multinomial distribution.
'mn'	Multinomial bag-of-tokens model.

gmdistribution.DistName property

Purpose Type of distribution

Description The string 'gaussian mixture distribution'.

disttool

Purpose Interactive density and distribution plots

Syntax `disttool`

Description `disttool` is a graphical interface for exploring the effects of changing parameters on the plot of a cdf or pdf.

See Also `randtool` | `dfittool`

Purpose Convert categorical array to double array

Syntax `B = double(A)`

Description `B = double(A)` converts the categorical array `A` to a double array. Each element of `B` contains the internal categorical level code for the corresponding element of `A`.

See Also `single`

dataset.double

Purpose Convert dataset variables to double array

Syntax `b = double(A)`
`b = double(a,vars)`

Description `b = double(A)` returns the contents of the dataset A, converted to one double array. The classes of the variables in the dataset must support the conversion.

`b = double(a,vars)` returns the contents of the dataset variables specified by vars. vars is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector.

See Also `dataset` | `single` | `replacedata`

Purpose

Drop levels

Syntax

```
B = droplevels(A)
B = droplevels(A,oldlevels)
```

Description

`B = droplevels(A)` removes unused levels from the categorical array `A`. `B` is a categorical array with the same size and values as `A`, but with a list of potential levels that includes only those present in some element of `A`.

`B = droplevels(A,oldlevels)` removes specified levels from the categorical array `A`. `oldlevels` is a cell array of strings or a 2-D character matrix specifying the levels to be removed.

`droplevels` removes levels, but does not remove elements. Elements of `B` that correspond to elements of `A` having levels in `oldlevels` all have an undefined level.

Examples

Example 1

Drop unused age levels from the data in `hospital.mat`:

```
load hospital
edges = 0:10:100;
labels = strcat(num2str((0:10:90)','%d'),{'s'});
AgeGroup = ordinal(hospital.Age,labels,[],edges);
AgeGroup = droplevels(AgeGroup);
getlabels(AgeGroup)
ans =
    '20s'    '30s'    '40s'    '50s'
```

Example 2

- 1 Load patient data from the CSV file `hospital.dat` and store the information in a dataset array with observation names given by the first column in the data (patient identification):

```
patients = dataset('file','hospital.dat',...
                  'delimiter',';',...)
```

categorical.droplevels

```
'ReadObsNames', true);
```

- 2 Make the {0,1}-valued variable `smoke` nominal, and change the labels to 'No' and 'Yes':

```
patients.smoke = nominal(patients.smoke, {'No', 'Yes'});
```

- 3 Add new levels to `smoke` as placeholders for more detailed histories of smokers:

```
patients.smoke = addlevels(patients.smoke, ...  
                           {'0-5 Years', '5-10 Years', 'LongTerm'});
```

- 4 Assuming the nonsmokers have never smoked, relabel the 'No' level:

```
patients.smoke = setlabels(patients.smoke, 'Never', 'No');
```

- 5 Drop the undifferentiated 'Yes' level from `smoke`:

```
patients.smoke = droplevels(patients.smoke, 'Yes');
```

Warning: OLDLEVELS contains categorical levels that were present in A, caused some array elements to have undefined levels.

Note that smokers now have an undefined level.

- 6 Set each smoker to one of the new levels, by observation name:

```
patients.smoke('YPL-320') = '5-10 Years';
```

See Also

`addlevels` | `getlabels` | `islevel` | `mergelevels` | `reorderlevels`

Purpose	Create dummy variables
Syntax	<code>D = dummyvar(group)</code>
Description	<p><code>D = dummyvar(group)</code> returns a matrix <code>D</code> containing zeros and ones, whose columns are dummy variables for the grouping variable <code>group</code>. Columns of <code>group</code> represent categorical predictor variables, with values indicating categorical levels. Rows of <code>group</code> represent observations across variables.</p> <p><code>group</code> can be a numeric vector or categorical column vector representing levels within a single variable, a cell array containing one or more grouping variables, or a numeric matrix or cell array of categorical column vectors representing levels within multiple variables. If <code>group</code> is a numeric vector or matrix, values in any column must be positive integers in the range from 1 to the number of levels for the corresponding variable. In this case, <code>dummyvars</code> treats each column as a separate numeric grouping variable. With multiple grouping variables, the sets of dummy variable columns are in the same order as the grouping variables in <code>group</code>.</p> <p>The order of the dummy variable columns in <code>D</code> matches the order of the groups defined by <code>group</code>. When <code>group</code> is a categorical vector, the groups and their order match the output of the <code>getlabels(group)</code> method. When <code>group</code> is a numeric vector, <code>dummyvar</code> assumes that the groups and their order are <code>1:max(group)</code>. In this respect, <code>dummyvars</code> treats a numeric grouping variable differently than <code>grp2idx</code>.</p> <p>If <code>group</code> is n-by-p, <code>D</code> is n-by-S, where S is the sum of the number of levels in each of the columns of <code>group</code>. The number of levels s in any column of <code>group</code> is the maximum positive integer in the column or the number of categorical levels. Levels are considered distinct if they appear in different columns of <code>group</code>, even if they have the same value. Columns of <code>D</code> are, from left to right, dummy variables created from the first column of <code>group</code>, followed by dummy variables created from the second column of <code>group</code>, etc.</p> <p><code>dummyvar</code> treats NaN values or undefined categorical levels in <code>group</code> as missing data and returns NaN values in <code>D</code>.</p>

dummyvar

Dummy variables are used in regression analysis and ANOVA to indicate values of categorical predictors.

Note If a column of 1s is introduced in the matrix D , the resulting matrix $X = [\text{ones}(\text{size}(D,1),1) \ D]$ will be rank deficient. The matrix D itself will be rank deficient if `group` has multiple columns. This is because dummy variables produced from any column of `group` always sum to a column of 1s. Regression and ANOVA calculations often address this issue by eliminating one dummy variable (implicitly setting the coefficients for dropped columns to zero) from each group of dummy variables produced by a column of `group`.

Examples

Suppose you are studying the effects of two machines and three operators on a process. Use `group` to organize predictor data on machine-operator combinations:

```
machine = [1 1 1 1 2 2 2 2]';
operator = [1 2 3 1 2 3 1 2]';
group = [machine operator]
group =
     1     1
     1     2
     1     3
     1     1
     2     2
     2     3
     2     1
     2     2
```

Use `dummyvar` to create dummy variables for a regression or ANOVA calculation:

```
D = dummyvar(group)
D =
     1     0     1     0     0
```

1	0	0	1	0
1	0	0	0	1
1	0	1	0	0
0	1	0	1	0
0	1	0	0	1
0	1	1	0	0
0	1	0	1	0

The first two columns of D represent observations of machine 1 and machine 2, respectively; the remaining columns represent observations of the three operators.

See Also

`regress` | `anova1`

How To

- “Grouping Variables” on page 2-72
- “Dummy Indicator Variables” on page 2-76
- “Regression with Categorical Covariates” on page 2-80

dwtest

Purpose Durbin-Watson test

Syntax
`[P,DW] = dwtest(R,X)`
`[...] = dwtest(R,X,method)`
`[...] = dwtest(R,X,method,tail)`

Description `[P,DW] = dwtest(R,X)` performs a Durbin-Watson test on the vector `R` of residuals from a linear regression, where `X` is the design matrix from that linear regression. `P` is the computed `p` value for the test, and `DW` is the Durbin-Watson statistic. The Durbin-Watson test is used to test if the residuals are uncorrelated, against the alternative that there is autocorrelation among them. Small values of `P` indicate that the residuals are correlated.

`[...] = dwtest(R,X,method)` specifies the method to be used in computing the `p` value. `method` can be either of the following:

- 'exact' — Calculates an exact `p` value using the PAN algorithm (the default if the sample size is less than 400).
- 'approximate' — Calculates the `p` value using a normal approximation (the default if the sample size is 400 or larger).

`[...] = dwtest(R,X,method,tail)` performs the test against one of the following alternative hypotheses, specified by `tail`:

Tail	Alternative Hypothesis
'both'	Serial correlation is not 0.
'right'	Serial correlation is greater than 0 (right-tailed test).
'left'	Serial correlation is less than 0 (left-tailed test).

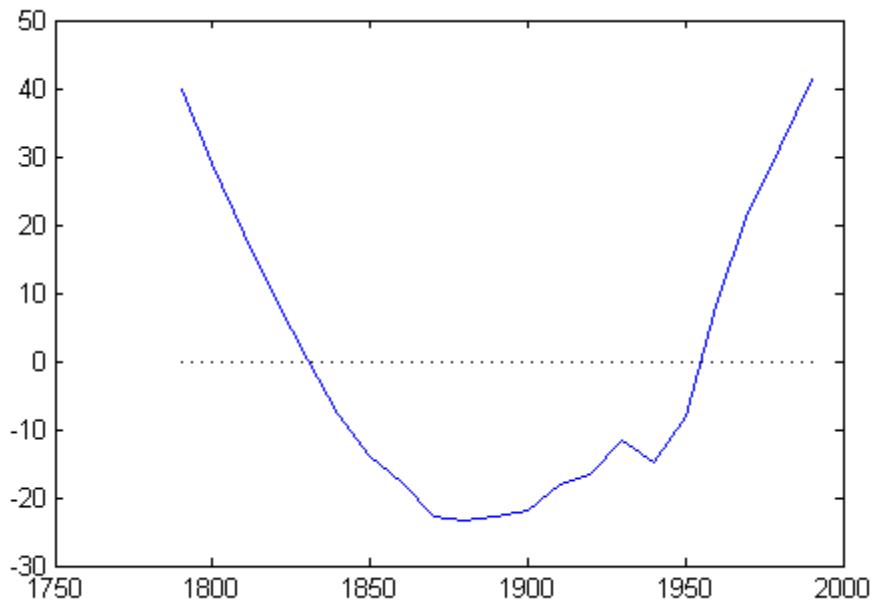
Examples Fit a straight line to the census data, plot the residuals, and note their autocorrelation:

```
load census
n = length(cdate);
X = [ones(n,1),cdate];
```

```
[b,bint,r1] = regress(pop,X);
p1 = dwtest(r1,X)
plot(cdate,r1,'b-',cdate,zeros(n,1),'k:')
```

```
p1 =
    0
```

The test strongly rejects the hypothesis of no correlation in the residuals.

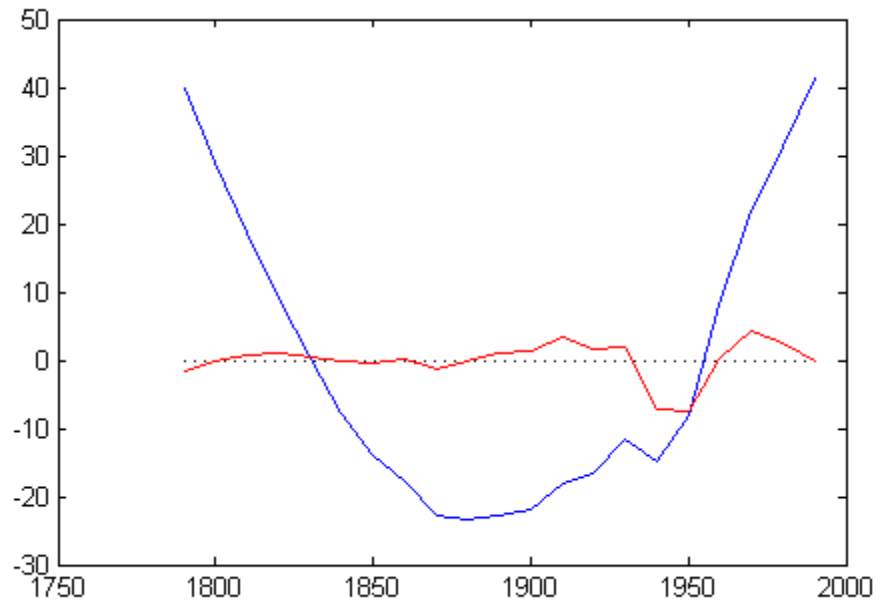


Adding a squared term gives less correlation in the residuals, but the resulting p value is still significantly small:

```
X = [ones(n,1),cdate,cdate.^2];
[b,bint,r2] = regress(pop,X);
p2 = dwtest(r2,X)
line(cdate,r2,'color','r')
```

dwtest

p2 =
0.0041



References

- [1] Durbin, J., and G. S. Watson. *Testing for Serial Correlation in Least Squares Regression I*. *Biometrika* 37, pp. 409–428, 1950.
- [2] Farebrother, R. W. *Pan's Procedure for the Tail Probabilities of the Durbin-Watson Statistic*. *Applied Statistics* 29, pp. 224–227, 1980.

See Also

regress

Purpose

Durbin-Watson test of linear model

Syntax

```
P = dwtest mdl
[P,DW] = dwtest mdl
[P,DW] = dwtest mdl,method
[P,DW] = dwtest mdl,method,tail
```

Description

`P = dwtest(mdl)` returns the p -value of the Durbin-Watson test on the `mdl` linear model.

`[P,DW] = dwtest(mdl)` returns the Durbin-Watson statistic.

`[P,DW] = dwtest(mdl,method)` specifies the method `dwtest` uses to compute the p -value.

`[P,DW] = dwtest(mdl,method,tail)` specifies the alternative hypothesis.

Input Arguments**mdl**

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

method

Algorithm for computing the p -value:

- 'exact' — Calculates an exact p -value using Pan's algorithm.
- 'approximate' — Calculates the p -value using a normal approximation.

Default: 'exact' when the sample size is less than 400, 'approximate' otherwise

tail

`dwtest` tests whether `mdl` has no serial correlation against one of these alternative hypotheses:

LinearModel.dwtest

Tail	Alternative Hypothesis
'both'	Serial correlation is not 0.
'right'	Serial correlation is greater than 0 (right-tailed test).
'left'	Serial correlation is less than 0 (left-tailed test).

Default: 'both'

Output Arguments

P

p-value of the test, a scalar. `dwtest` tests if the residuals are uncorrelated, against the alternative that there is autocorrelation among them. Small values of P indicate that the residuals are correlated.

DW

Value of the Durbin-Watson statistic, a scalar.

Definitions

Durbin-Watson Statistic

Let r be the vector of residuals (in `mdl.residuals.response`). The Durbin-Watson statistic is

$$DW = \frac{\sum_{i=1}^{n-1} (r_{i+1} - r_i)^2}{\sum_{i=1}^n r_i^2}.$$

Examples

Test Residuals for Autocorrelation

Examine whether the residuals from a fitted model of census data over time have autocorrelated residuals.

Load the census data and create a linear model.

```
load census
mdl = LinearModel.fit(cdate, pop);
```

Find the p -value of the Durbin-Watson autocorrelation test.

```
P = dwtest(mdl)
```

```
P =
```

```
0
```

There is significant autocorrelation in the residuals.

Algorithms

Approximate calculation of the p -value uses a normal approximation [1]. Exact calculation uses Pan's algorithm [2].

References

- [1] Durbin, J., and G. S. Watson. *Testing for Serial Correlation in Least Squares Regression I*. *Biometrika* 37, pp. 409–428, 1950.
- [2] Farebrother, R. W. *Pan's Procedure for the Tail Probabilities of the Durbin-Watson Statistic*. *Applied Statistics* 29, pp. 224–227, 1980.

See Also

LinearModel

How To

- “Linear Regression” on page 9-7

ecdf

Purpose Empirical cumulative distribution function

Syntax

```
[f,x] = ecdf(y)
[f,x,flo,fup] = ecdf(y)
ecdf(...)
ecdf(ax,...)
[...] = ecdf(y,param1,val1,param2,val2,...)
```

Description `[f,x] = ecdf(y)` calculates the Kaplan-Meier estimate of the cumulative distribution function (cdf), also known as the empirical cdf. `y` is a vector of data values. `f` is a vector of values of the empirical cdf evaluated at `x`.

`[f,x,flo,fup] = ecdf(y)` also returns lower and upper confidence bounds for the cdf. These bounds are calculated using Greenwood's formula, and are not simultaneous confidence bounds.

`ecdf(...)` without output arguments produces a plot of the empirical cdf.

`ecdf(ax,...)` plots into axes `ax` instead of `gca`.

`[...] = ecdf(y,param1,val1,param2,val2,...)` specifies additional parameter/value pairs chosen from the following:

Parameter	Value
'censoring'	Boolean vector of the same size as <code>x</code> . Elements are 1 for observations that are right-censored and 0 for observations that are observed exactly. Default is all observations observed exactly.
'frequency'	Vector of the same size as <code>x</code> containing nonnegative integer counts. The <code>j</code> th element of this vector gives the number of times the <code>j</code> th element of <code>x</code> was observed. Default is 1 observation per element of <code>x</code> .
'alpha'	Value between 0 and 1 for a confidence level of $100(1-\text{alpha})\%$. Default is <code>alpha=0.05</code> for 95% confidence.

Parameter	Value
'function'	Type of function returned as the f output argument, chosen from 'cdf' (default), 'survivor', or 'cumulative hazard'.
'bounds'	Either 'on' to include bounds, or 'off' (the default) to omit them. Used only for plotting.

Examples

Generate random failure times and random censoring times, and compare the empirical cdf with the known true cdf:

```

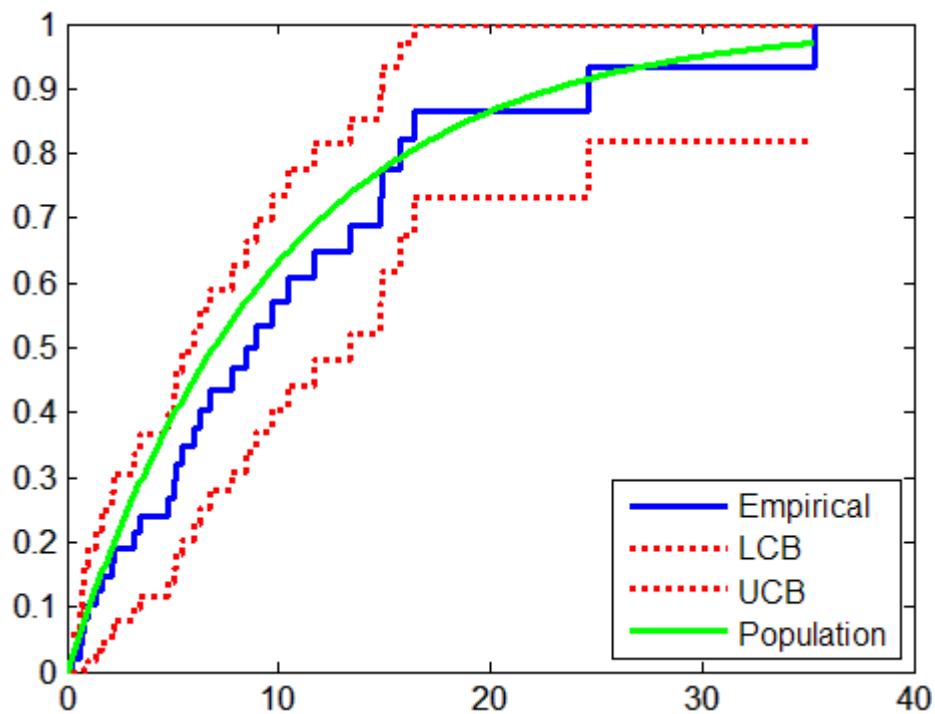
y = exprnd(10,50,1); % Random failure times exponential(10)
d = exprnd(20,50,1); % Drop-out times exponential(20)
t = min(y,d); % Observe the minimum of these times
censored = (y>d); % Observe whether the subject failed

% Calculate and plot empirical cdf and confidence bounds
[f,x,flo,fup] = ecdf(t,'censoring',censored);
stairs(x,f,'LineWidth',2)
hold on
stairs(x,flo,'r:', 'LineWidth',2)
stairs(x,fup,'r:', 'LineWidth',2)

% Superimpose a plot of the known population cdf
xx = 0:.1:max(t);
yy = 1-exp(-xx/10);
plot(xx,yy,'g-', 'LineWidth',2)
legend('Empirical','LCB','UCB','Population',...
       'Location','SE')
hold off

```

ecdf



References

[1] Cox, D. R., and D. Oakes. *Analysis of Survival Data*. London: Chapman & Hall, 1984.

See Also

`cdfplot` | `ecdfhist`

Purpose

Empirical cumulative distribution function histogram

Syntax

```
n = ecdfhist(f,x)
n = ecdfhist(f,x,m)
n = ecdfhist(f,x,c)
[n,c] = ecdfhist(...)
ecdfhist(...)
```

Description

`n = ecdfhist(f,x)` takes a vector `f` of empirical cumulative distribution function (cdf) values and a vector `x` of evaluation points, and returns a vector `n` containing the heights of histogram bars for 10 equally spaced bins. The function computes the bar heights from the increases in the empirical cdf, and normalizes them so that the area of the histogram is equal to 1. In contrast, `hist` produces bars whose heights represent bin counts.

`n = ecdfhist(f,x,m)`, where `m` is a scalar, uses `m` bins.

`n = ecdfhist(f,x,c)`, where `c` is a vector, uses bins with centers specified by `c`.

`[n,c] = ecdfhist(...)` also returns the position of the bin centers in `c`.

`ecdfhist(...)` without output arguments produces a histogram bar plot of the results.

Examples

The following code generates random failure times and random censoring times, and compares the empirical pdf with the known true pdf.

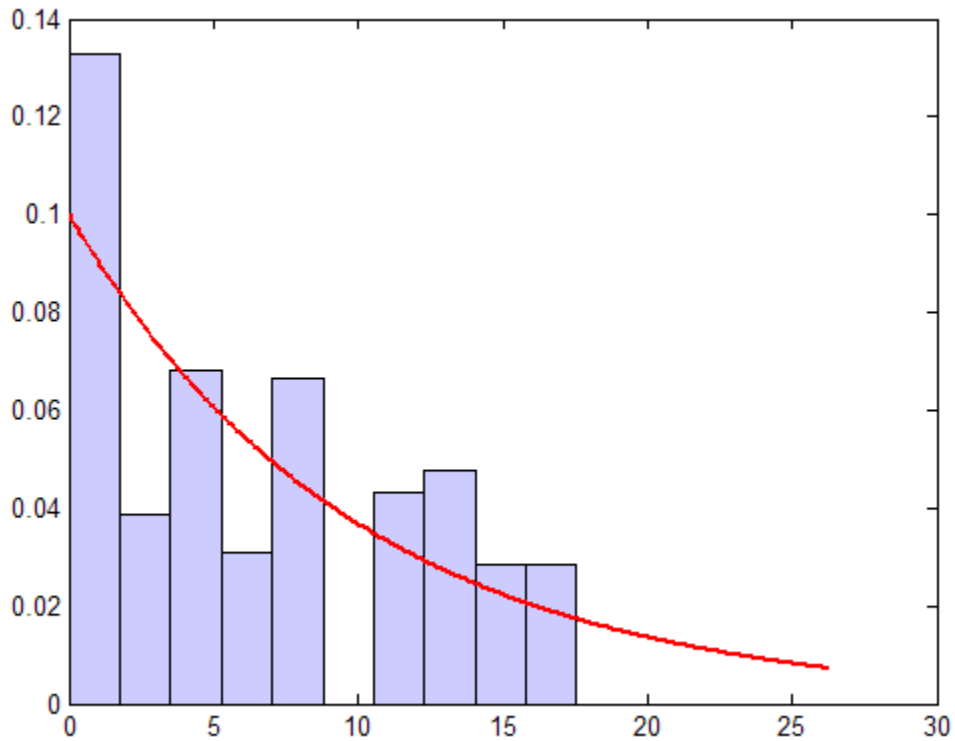
```
y = exprnd(10,50,1); % Random failure times
d = exprnd(20,50,1); % Drop-out times
t = min(y,d);        % Observe the minimum of these times
censored = (y>d);    % Observe whether the subject failed

% Calculate the empirical cdf and plot a histogram from it
[f,x] = ecdf(t,'censoring',censored);
ecdfhist(f,x)
```

ecdfhist

```
set(get(gca,'Children'),'FaceColor',[.8 .8 1])
hold on

% Superimpose a plot of the known population pdf
xx = 0:.1:max(t);
yy = exp(-xx/10)/10;
plot(xx,yy,'r-','LineWidth',2)
hold off
```



See Also [ecdf](#) | [hist](#) | [histc](#)

Purpose

Edge of k -nearest neighbor classifier

Syntax

```
E = edge(md1,X,Y)
E = edge(md1,X,Y,Name,Value)
```

Description

`E = edge(md1,X,Y)` returns the classification edge for `md1` with data `X` and classification `Y`.

`E = edge(md1,X,Y,Name,Value)` computes the edge with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

md1

k -nearest neighbor classifier, created by `ClassificationKNN.fit`.

X

Matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

Y

Grouping variables of response values with the same number of elements (rows) as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

weights

Observation weights, a numeric vector of length `size(X,1)`. If you supply `weights`, `edge` computes weighted classification edge.

Default: `ones(size(X,1))`

ClassificationKNN.edge

Output Arguments

E

Classification edge, a scalar that is the mean classification margin (see “Margin” on page 20-568).

Definitions

Edge

The *edge* is the mean value of the classification *margin*.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes.

Margin is a column vector with the same number of rows as *X*.

Score

The *score* of a classification is the posterior probability of the classification. The posterior probability is the number of neighbors that have that classification, divided by the number of neighbors. For a more detailed definition that includes weights and prior probabilities, see “Posterior Probability” on page 20-1830.

Examples

Edge Calculation

Construct a *k*-nearest neighbor classifier for the Fisher iris data, where *k* = 5.

Load the data.

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for five-nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',5);
```

Examine the edge of the classifier for minimum, mean, and maximum observations classified 'setosa', 'versicolor', and 'virginica' respectively.

```
NewX = [min(X);mean(X);max(X)];  
Y = {'setosa';'versicolor';'virginica'};  
E = edge mdl,NewX,Y
```

```
E =
```

```
1
```

The classifier has no doubt that the Y entries are correct classifications (all five nearest neighbors of each NewX point classify as the corresponding Y entry).

See Also

[ClassificationKNN](#) | [ClassificationKNN.fit](#) | [loss](#) | [margin](#) |

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

CompactClassificationDiscriminant.edge

Purpose	Classification edge
Syntax	<code>E = edge(obj,X,Y)</code> <code>E = edge(obj,X,Y,Name,Value)</code>
Description	<code>E = edge(obj,X,Y)</code> returns the classification edge for <code>obj</code> with data <code>X</code> and classification <code>Y</code> . <code>E = edge(obj,X,Y,Name,Value)</code> computes the edge with additional options specified by one or more <code>Name,Value</code> pair arguments.
Input Arguments	obj Discriminant analysis classifier of class <code>ClassificationDiscriminant</code> or <code>CompactClassificationDiscriminant</code> , typically constructed with <code>ClassificationDiscriminant.fit</code> . X Matrix where each row represents an observation, and each column represents a predictor. The number of columns in <code>X</code> must equal the number of predictors in <code>obj</code> . Y Class labels, with the same data type as exists in <code>obj</code> . The number of elements of <code>Y</code> must equal the number of rows of <code>X</code> . Name-Value Pair Arguments Specify optional comma-separated pairs of <code>Name,Value</code> arguments, where <code>Name</code> is the argument name and <code>Value</code> is the corresponding value. <code>Name</code> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <code>Name1,Value1,...,NameN,ValueN</code> . weights Observation weights, a numeric vector of length <code>size(X,1)</code> . If you supply weights, <code>edge</code> computes the weighted classification edge.

Default: `ones(size(X,1))`

Output Arguments

E

Edge, a scalar representing the weighted average value of the margin.

Definitions

Edge

The *edge* is the weighted mean value of the classification *margin*. The weights are the class probabilities in `Obj.Prior`. If you supply weights in the `weights` name-value pair, those weights are normalized to sum to the prior probabilities in the respective classes, and are then used to compute the weighted average.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `X`. A high value of margin indicates a more reliable prediction than a low value.

Score (discriminant analysis)

For discriminant analysis, the *score* of a classification is the posterior probability of the classification. For the definition of posterior probability in discriminant analysis, see “Posterior Probability” on page 12-7.

Examples

Compute the classification edge and margin for the Fisher iris data, trained on its first two columns of data, and view the last 10 entries:

```
load fisheriris
X = meas(:,1:2);
obj = ClassificationDiscriminant.fit(X,species);
E = edge(obj,X,species)
```

```
E =
    0.4980
```

CompactClassificationDiscriminant.edge

```
M = margin(obj,X,species);  
M(end-10:end)
```

```
ans =  
    0.6551  
    0.4838  
    0.6551  
   -0.5127  
    0.5659  
    0.4611  
    0.4949  
    0.1024  
    0.2787  
   -0.1439  
   -0.4444
```

The classifier trained on all the data is better:

```
obj = ClassificationDiscriminant.fit(meas,species);  
E = edge(obj,meas,species)
```

```
E =  
    0.9454
```

```
M = margin(obj,meas,species);  
M(end-10:end)
```

```
ans =  
    0.9983  
    1.0000  
    0.9991  
    0.9978  
    1.0000  
    1.0000  
    0.9999  
    0.9882
```

0.9937
1.0000
0.9649

See Also

ClassificationDiscriminant | loss | margin | predict

How To

- “Discriminant Analysis” on page 12-3

CompactClassificationEnsemble.edge

Purpose	Classification edge
Syntax	<code>E = edge(ens,X,Y)</code> <code>E = edge(ens,X,Y,Name,Value)</code>
Description	<code>E = edge(ens,X,Y)</code> returns the classification edge for <code>ens</code> with data <code>X</code> and classification <code>Y</code> . <code>E = edge(ens,X,Y,Name,Value)</code> computes the edge with additional options specified by one or more <code>Name,Value</code> pair arguments.
Input Arguments	ens A classification ensemble constructed with <code>fitensemble</code> , or a compact classification ensemble constructed with <code>compact</code> . X A matrix where each row represents an observation, and each column represents a predictor. The number of columns in <code>X</code> must equal the number of predictors in <code>ens</code> . Y Class labels, with the same data type as exists in <code>ens</code> . The number of elements of <code>Y</code> must equal the number of rows of <code>X</code> . Name-Value Pair Arguments Specify optional comma-separated pairs of <code>Name,Value</code> arguments, where <code>Name</code> is the argument name and <code>Value</code> is the corresponding value. <code>Name</code> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <code>Name1,Value1,...,NameN,ValueN</code> . learners Indices of weak learners in the ensemble ranging from 1 to <code>ens.NTrained</code> . <code>edge</code> uses only these learners for calculating loss. Default: <code>1:NTrained</code>

mode

String representing the meaning of the output E:

- 'ensemble' — E is a scalar value, the edge for the entire ensemble.
- 'individual' — E is a vector with one element per trained learner.
- 'cumulative' — E is a vector in which element J is obtained by using learners 1:J from the input list of learners.

Default: 'ensemble'

UseObsForLearner

A logical matrix of size N-by-T, where:

- N is the number of rows of X.
- T is the number of weak learners in ens.

When `UseObsForLearner(i,j)` is true, learner j is used in predicting the class of row i of X.

Default: `true(N,T)`

weights

Observation weights, a numeric vector of length `size(X,1)`. If you supply weights, `edge` computes weighted classification edge.

Default: `ones(size(X,1))`

Output Arguments

E

The classification edge, a vector or scalar depending on the setting of the mode name-value pair. Classification edge is weighted average classification margin.

CompactClassificationEnsemble.edge

Definitions

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix *X*.

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

Edge

The *edge* is the weighted mean value of the classification margin. The weights are the class probabilities in `ens.Prior`. If you supply weights in the `weights` name-value pair, those weights are used instead of class probabilities.

Examples

Make a boosted ensemble classifier for the `ionosphere` data, and find the classification edge for the last few rows:

```
load ionosphere
ens = fitensemble(X,Y,'AdaboostM1',100,'Tree');
E = edge(ens,X(end-10:end,:),Y(end-10:end))
```

```
E =
    8.3310
```

See Also

`margin` | `edge`

Purpose

Classification edge

Syntax

```
E = edge(tree,X,Y)
E = edge(tree,X,Y,Name,Value)
```

Description

`E = edge(tree,X,Y)` returns the classification edge for `tree` with data `X` and classification `Y`.

`E = edge(tree,X,Y,Name,Value)` computes the edge with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments**tree**

A classification tree created by `ClassificationTree.fit`, or a compact classification tree created by `compact`.

X

A matrix where each row represents an observation, and each column represents a predictor. The number of columns in `X` must equal the number of predictors in `tree`.

Y

Class labels, with the same data type as exists in `tree`. The number of elements of `Y` must equal the number of rows of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

weights

Observation weights, a numeric vector of length `size(X,1)`. If you supply `weights`, `edge` computes weighted classification edge.

Default: `ones(size(X,1))`

CompactClassificationTree.edge

Output Arguments

E

The edge, a scalar representing the weighted average value of the margin.

Definitions

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as the matrix X.

Score (tree)

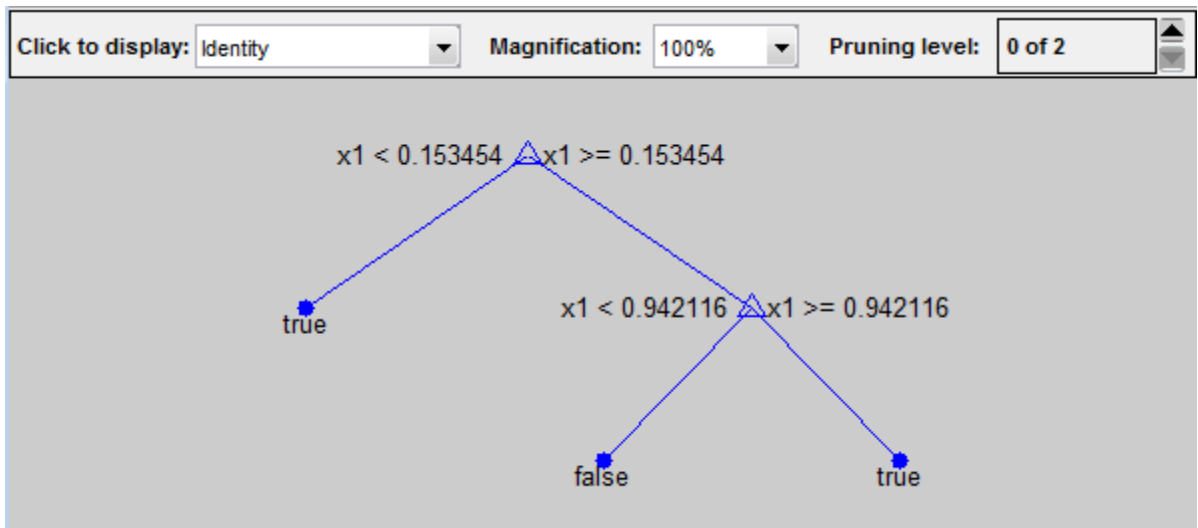
For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```

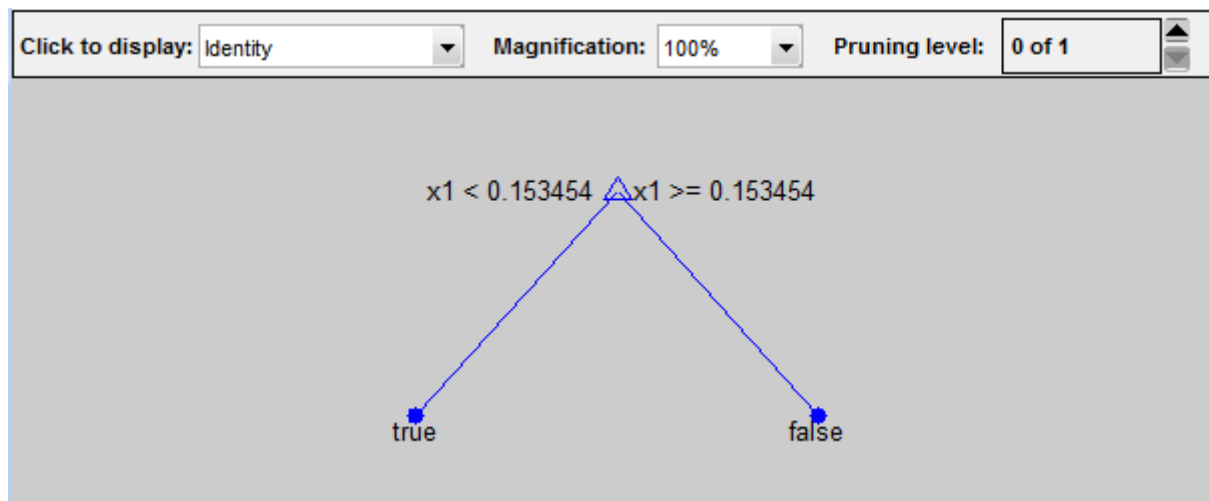


2

Prune the tree:

```
tree1 = prune(tree, 'level', 1);  
view(tree1, 'mode', 'graph')
```

CompactClassificationTree.edge



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
    0.9059    0.0941    0.8147  
    0.9059    0.0941    0.9058  
         0    1.0000    0.1270  
    0.9059    0.0941    0.9134  
    0.9059    0.0941    0.6324  
         0    1.0000    0.0975  
    0.9059    0.0941    0.2785
```

```
0.9059    0.0941    0.5469
0.9059    0.0941    0.9575
0.9059    0.0941    0.9649
```

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range (.95, 1) instead of the expected 5 observations.

Edge

The *edge* is the weighted mean value of the classification margin. The weights are the class probabilities in `tree.Prior`. If you supply weights in the `weights` name-value pair, those weights are normalized to sum to the prior probabilities in the respective classes, and are then used to compute the weighted average.

Examples

Compute the classification margin and edge for the Fisher iris data, trained on its first two columns of data, and view the last 10 entries:

```
load fisheriris
X = meas(:,1:2);
tree = ClassificationTree.fit(X,species);
E = edge(tree,X,species)

E =
    0.6299

M = margin(tree,X,species);
M(end-10:end)

ans =
    0.1111
    0.1111
    0.1111
   -0.2857
```

CompactClassificationTree.edge

```
0.6364
0.6364
0.1111
0.7500
1.0000
0.6364
0.2000
```

The classification tree trained on all the data is better:

```
tree = ClassificationTree.fit(meas,species);
E = edge(tree,meas,species)
```

```
E =
    0.9384
```

```
M = margin(tree,meas,species);
M(end-10:end)
```

```
ans =
    0.9565
    0.9565
    0.9565
    0.9565
    0.9565
    0.9565
    0.9565
    0.9565
    0.9565
    0.9565
    0.9565
```

See Also

[margin](#) | [loss](#) | [predict](#)

Purpose Last index in indexing expression for categorical array

Syntax `end(A,k,n)`

Description `end(A,k,n)` indexes expressions involving the categorical array `A` when `end` is part of the `k`-th index out of `n` indices. For example, the expression `A(end-1,:)` calls `A`'s `end` method with `end(A,1,2)`.

See Also `single`

dataset.end

Purpose Last index in indexing expression for dataset array

Syntax `end(A,k,n)`

Description `end(A,k,n)` is called for indexing expressions involving the dataset A when `end` is part of the k-th index out of n indices. For example, the expression `A(end-1,:)` calls A's `end` method with `end(A,1,2)`.

See Also `size`

Purpose Last index in indexing expression for point set

Syntax `end(p,k,n)`

Description `end(p,k,n)` is called for indexing expressions involving the point set `p` when `end` is part of the `k`-th index out of `n` indices. For example, the expression `p(end-1,:)` calls `p`'s `end` method with `end(p,1,2)`.

See Also `grandset`

Purpose Extreme value cumulative distribution function

Syntax `P = evcdf(X,mu,sigma)`
`[P,PL0,PUP] = evcdf(X,mu,sigma,pcov,alpha)`

Description `P = evcdf(X,mu,sigma)` computes the cumulative distribution function (cdf) for the type 1 extreme value distribution, with location parameter `mu` and scale parameter `sigma`, at each of the values in `X`. `X`, `mu`, and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other inputs. The default values for `mu` and `sigma` are 0 and 1, respectively.

`[P,PL0,PUP] = evcdf(X,mu,sigma,pcov,alpha)` produces confidence bounds for `P` when the input parameters `mu` and `sigma` are estimates. `pcov` is a 2-by-2 covariance matrix of the estimated parameters. `alpha` has a default value of 0.05, and specifies $100(1 - \alpha)\%$ confidence bounds. `PL0` and `PUP` are arrays of the same size as `P`, containing the lower and upper confidence bounds.

The function `evcdf` computes confidence bounds for `P` using a normal approximation to the distribution of the estimate

$$\frac{X - \hat{\mu}}{\hat{\sigma}}$$

and then transforming those bounds to the scale of the output `P`. The computed bounds give approximately the desired confidence level when you estimate `mu`, `sigma`, and `pcov` from large samples, but in smaller samples other methods of computing the confidence bounds might be more accurate.

The type 1 extreme value distribution is also known as the Gumbel distribution. The version used here is suitable for modeling minima; the mirror image of this distribution can be used to model maxima by negating `X`. See “Extreme Value Distribution” on page B-32 for more details. If `x` has a Weibull distribution, then `X = log(x)` has the type 1 extreme value distribution.

See Also

`cdf` | `evpdf` | `evinv` | `evstat` | `evfit` | `evlike` | `evrnd`

How To

- “Extreme Value Distribution” on page B-32

Purpose Extreme value parameter estimates

Syntax

```
parmhat = evfit(data)
[parmhat,parmci] = evfit(data)
[parmhat,parmci] = evfit(data,alpha)
[...] = evfit(data,alpha,censoring)
[...] = evfit(data,alpha,censoring,freq)
[...] = evfit(data,alpha,censoring,freq,options)
```

Description `parmhat = evfit(data)` returns maximum likelihood estimates of the parameters of the type 1 extreme value distribution given the data in the vector `data`. `parmhat(1)` is the location parameter, μ , and `parmhat(2)` is the scale parameter, σ .

`[parmhat,parmci] = evfit(data)` returns 95% confidence intervals for the parameter estimates on the μ and σ parameters in the 2-by-2 matrix `parmci`. The first column of the matrix of the extreme value fit contains the lower and upper confidence bounds for the parameter μ , and the second column contains the confidence bounds for the parameter σ .

`[parmhat,parmci] = evfit(data,alpha)` returns $100(1 - \text{alpha})\%$ confidence intervals for the parameter estimates, where `alpha` is a value in the range `[0 1]` specifying the width of the confidence intervals. By default, `alpha` is 0.05, which corresponds to 95% confidence intervals.

`[...] = evfit(data,alpha,censoring)` accepts a Boolean vector, `censoring`, of the same size as `data`, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.

`[...] = evfit(data,alpha,censoring,freq)` accepts a frequency vector, `freq` of the same size as `data`. Typically, `freq` contains integer frequencies for the corresponding elements in `data`, but can contain any nonnegative values. Pass in `[]` for `alpha`, `censoring`, or `freq` to use their default values.

`[...] = evfit(data,alpha,censoring,freq,options)` accepts a structure, `options`, that specifies control parameters for the iterative algorithm the function uses to compute maximum likelihood

estimates. You can create options using the function `statset`. Enter `statset('evfit')` to see the names and default values of the parameters that `evfit` accepts in the options structure. See the reference page for `statset` for more information about these options.

The type 1 extreme value distribution is also known as the Gumbel distribution. The version used here is suitable for modeling minima; the mirror image of this distribution can be used to model maxima by negating X . See “Extreme Value Distribution” on page B-32 for more details. If x has a Weibull distribution, then $X = \log(x)$ has the type 1 extreme value distribution.

See Also

`mle` | `evlike` | `evpdf` | `evcdf` | `evinv` | `evstat` | `evrnd`

How To

- “Extreme Value Distribution” on page B-32

Purpose Extreme value inverse cumulative distribution function

Syntax
`X = evinv(P,mu,sigma)`
`[X,XLO,XUP] = evinv(P,mu,sigma,pcov,alpha)`

Description `X = evinv(P,mu,sigma)` returns the inverse cumulative distribution function (cdf) for a type 1 extreme value distribution with location parameter `mu` and scale parameter `sigma`, evaluated at the values in `P`. `P`, `mu`, and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other inputs. The default values for `mu` and `sigma` are 0 and 1, respectively.

`[X,XLO,XUP] = evinv(P,mu,sigma,pcov,alpha)` produces confidence bounds for `X` when the input parameters `mu` and `sigma` are estimates. `pcov` is the covariance matrix of the estimated parameters. `alpha` is a scalar that specifies $100(1 - \alpha)\%$ confidence bounds for the estimated parameters, and has a default value of 0.05. `XLO` and `XUP` are arrays of the same size as `X` containing the lower and upper confidence bounds.

The function `evinv` computes confidence bounds for `P` using a normal approximation to the distribution of the estimate

$$\hat{\mu} + \hat{\sigma}q$$

where q is the P th quantile from an extreme value distribution with parameters $\mu = 0$ and $\sigma = 1$. The computed bounds give approximately the desired confidence level when you estimate `mu`, `sigma`, and `pcov` from large samples, but in smaller samples other methods of computing the confidence bounds might be more accurate.

The type 1 extreme value distribution is also known as the Gumbel distribution. The version used here is suitable for modeling minima; the mirror image of this distribution can be used to model maxima by negating X . See “Extreme Value Distribution” on page B-32 for more details. If x has a Weibull distribution, then $X = \log(x)$ has the type 1 extreme value distribution.

See Also

`icdf` | `evcdf` | `evpdf` | `evstat` | `evfit` | `evlike` | `evrnd`

Purpose Test handle equality

Syntax
`h1 == h2`
`tf = eq(h1, h2)`

Description `h1 == h2` performs element-wise comparisons between handle arrays `h1` and `h2`. `h1` and `h2` must be of the same dimensions unless one is a scalar. The result is a logical array of the same dimensions, where each element is an element-wise equality result. If one of `h1` or `h2` is scalar, scalar expansion is performed and the result will match the dimensions of the array that is not scalar.

`tf = eq(h1, h2)` stores the result in a logical array of the same dimensions.

See Also `grandstream` | `ge` | `gt` | `le` | `lt` | `ne`

Purpose

Error (misclassification probability or MSE)

Syntax

```
err = error(B,X,Y)
err = error(B,X,Y,'param1',val1,'param2',val2,...)
```

Description

`err = error(B,X,Y)` computes the misclassification probability (for classification trees) or mean squared error (MSE, for regression trees) for each tree, for predictors `X` given true response `Y`. For classification, `Y` can be either a numeric vector, character matrix, cell array of strings, categorical vector or logical vector. For regression, `Y` must be a numeric vector. `err` is a vector with one error measure for each of the `NTrees` trees in the ensemble `B`.

`err = error(B,X,Y,'param1',val1,'param2',val2,...)` specifies optional parameter name/value pairs:

- 'mode' String indicating how the method computes errors. If set to 'cumulative' (default), error computes cumulative errors and `err` is a vector of length `NTrees`, where the first element gives error from `trees(1)`, second element gives error from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to 'individual', `err` is a vector of length `NTrees`, where each element is an error from each tree in the ensemble. If set to 'ensemble', `err` is a scalar showing the cumulative error for the entire ensemble.
- 'trees' Vector of indices indicating what trees to include in this calculation. By default, this argument is set to 'all' and the method uses all trees. If 'trees' is a numeric vector, the method returns a vector of length `NTrees` for 'cumulative' and 'individual' modes, where `NTrees` is the number of elements in the input vector, and a scalar for 'ensemble' mode. For example, in the 'cumulative' mode, the first element gives error from `trees(1)`, the second element gives error from `trees(1:2)` etc.

CompactTreeBagger.error

- 'treeweights' Vector of tree weights. This vector must have the same length as the 'trees' vector. The method uses these weights to combine output from the specified trees by taking a weighted average instead of the simple non-weighted majority vote. You cannot use this argument in the 'individual' mode.
- 'useifort' Logical matrix of size Nobs-by-NTrees indicating which trees should be used to make predictions for each observation. By default the method uses all trees for all observations.

See Also

TreeBagger.error

Purpose

Error (misclassification probability or MSE)

Syntax

```
err = error(B,X,Y)
err = error(B,X,Y,'param1',val1,'param2',val2,...)
```

Description

`err = error(B,X,Y)` computes the misclassification probability for classification trees or mean squared error (MSE) for regression trees for each tree, for predictors `X` given true response `Y`. For classification, `Y` can be either a numeric vector, character matrix, cell array of strings, categorical vector or logical vector. For regression, `Y` must be a numeric vector. `err` is a vector with one error measure for each of the `NTrees` trees in the ensemble `B`.

`err = error(B,X,Y,'param1',val1,'param2',val2,...)` specifies optional parameter name/value pairs:

- 'mode' String indicating how the method computes errors. If set to 'cumulative' (default), error computes cumulative errors and `err` is a vector of length `NTrees`, where the first element gives error from `trees(1)`, second element gives error from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to 'individual', `err` is a vector of length `NTrees`, where each element is an error from each tree in the ensemble. If set to 'ensemble', `err` is a scalar showing the cumulative error for the entire ensemble.
- 'trees' Vector of indices indicating what trees to include in this calculation. By default, this argument is set to 'all' and the method uses all trees. If 'trees' is a numeric vector, the method returns a vector of length `NTrees` for 'cumulative' and 'individual' modes, where `NTrees` is the number of elements in the input vector, and a scalar for 'ensemble' mode. For example, in the 'cumulative' mode, the first element gives error from `trees(1)`, the second element gives error from `trees(1:2)` etc.

TreeBagger.error

- 'treeweights' Vector of tree weights. This vector must have the same length as the 'trees' vector. The method uses these weights to combine output from the specified trees by taking a weighted average instead of the simple non-weighted majority vote. You cannot use this argument in the 'individual' mode.
- 'useifort' Logical matrix of size Nobs-by-NTrees indicating which trees should be used to make predictions for each observation. By default the method uses all trees for all observations.

See Also

`CompactTreeBagger.error`

Purpose	Predicted responses
Syntax	<pre>yfit = eval(t,X) yfit = eval(t,X,s) [yfit,nodes] = eval(...) [yfit,nodes,cnums] = eval(...) [...] = t(X) [...] = t(X,s)</pre>
Description	<p><code>yfit = eval(t,X)</code> takes a classification or regression tree <code>t</code> and a matrix <code>X</code> of predictors, and produces a vector <code>yfit</code> of predicted response values. For a regression tree, <code>yfit(i)</code> is the fitted response value for a point having the predictor values <code>X(i,:)</code>. For a classification tree, <code>yfit(i)</code> is the class into which the tree assigns the point with data <code>X(i,:)</code>.</p> <p><code>yfit = eval(t,X,s)</code> takes an additional vector <code>s</code> of pruning levels, with 0 representing the full, unpruned tree. <code>t</code> must include a pruning sequence as created by <code>classregtree</code> or by <code>prune</code>. If <code>s</code> has k elements and <code>X</code> has n rows, the output <code>yfit</code> is an n-by-k matrix, with the jth column containing the fitted values produced by the <code>s(j)</code> subtree. <code>s</code> must be sorted in ascending order.</p> <p>To compute fitted values for a tree that is not part of the optimal pruning sequence, first use <code>prune</code> to prune the tree.</p> <p><code>[yfit,nodes] = eval(...)</code> also returns a vector <code>nodes</code> the same size as <code>yfit</code> containing the node number assigned to each row of <code>X</code>. Use <code>view</code> to display the node numbers for any node you select.</p> <p><code>[yfit,nodes,cnums] = eval(...)</code> is valid only for classification trees. It returns a vector <code>cnum</code> containing the predicted class numbers.</p> <p>NaN values in <code>X</code> are treated as missing. If <code>eval</code> encounters a missing value when it attempts to evaluate the split rule at a branch node, it cannot determine whether to proceed to the left or right child node. Instead, it sets the corresponding fitted value equal to the fitted value assigned to the branch node.</p> <p><code>[...] = t(X)</code> or <code>[...] = t(X,s)</code> also invoke <code>eval</code>.</p>

Examples

Create a classification tree for Fisher's iris data:

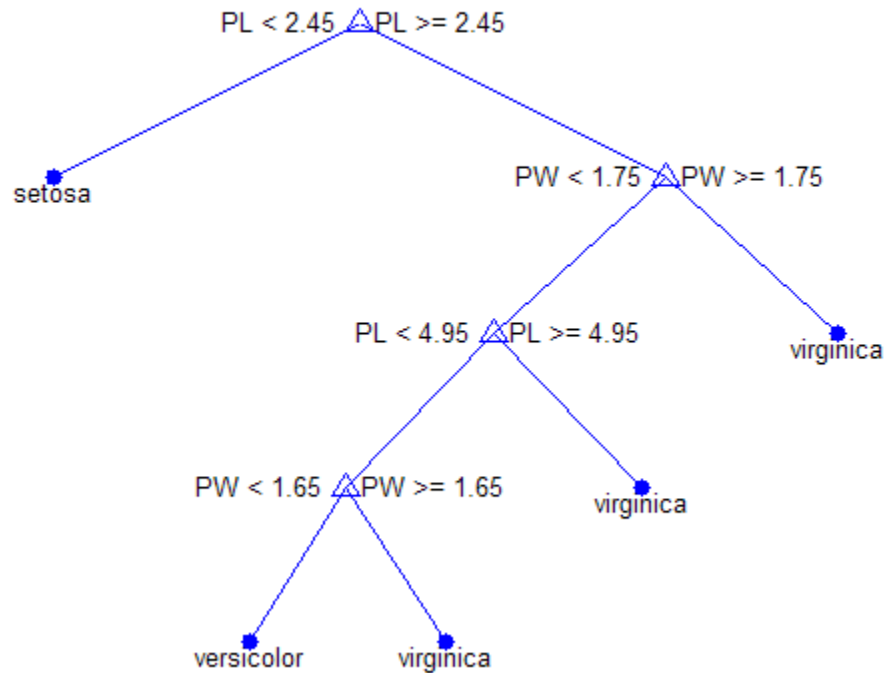
```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})

t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```


Click to display: Magnification: Pruning level:



Find assigned class names:

```
sfit = eval(t,meas);
```

Compute that proportion is correctly classified:

```
pct = mean(strcmp(sfit,species))
pct =
    0.9800
```

classregtree.eval

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

`classregtree` | `prune` | `test` | `view`

Purpose	Extreme value negative log-likelihood
Syntax	<pre>nlogL = evlike(params,data) [nlogL,AVAR] = evlike(params,data) [...] = evlike(params,data,censoring) [...] = evlike(params,data,censoring,freq)</pre>
Description	<p><code>nlogL = evlike(params,data)</code> returns the negative of the log-likelihood for the type 1 extreme value distribution. <code>params(1)</code> is the tail location parameter, <code>mu</code>, and <code>params(2)</code> is the scale parameter, <code>sigma</code>. <code>nlogL</code> is a scalar.</p> <p><code>[nlogL,AVAR] = evlike(params,data)</code> returns the inverse of Fisher's information matrix, <code>AVAR</code>. If the input parameter values in <code>params</code> are the maximum likelihood estimates, the diagonal elements of <code>AVAR</code> are their asymptotic variances. <code>AVAR</code> is based on the observed Fisher's information, not the expected information.</p> <p><code>[...] = evlike(params,data,censoring)</code> accepts a Boolean vector of the same size as <code>data</code>, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.</p> <p><code>[...] = evlike(params,data,censoring,freq)</code> accepts a frequency vector of the same size as <code>data</code>. <code>freq</code> typically contains integer frequencies for the corresponding elements in <code>data</code>, but can contain any nonnegative values. Pass in <code>[]</code> for <code>censoring</code> to use its default value.</p> <p>The type 1 extreme value distribution is also known as the Gumbel distribution. The version used here is suitable for modeling minima; the mirror image of this distribution can be used to model maxima by negating data. See “Extreme Value Distribution” on page B-32 for more details. If x has a Weibull distribution, then $X = \log(x)$ has the type 1 extreme value distribution.</p>
See Also	<code>evfit</code> <code>evpdf</code> <code>evcdf</code> <code>evinv</code> <code>evstat</code> <code>evrnd</code>
How To	<ul style="list-style-type: none">• “Extreme Value Distribution” on page B-32

evpdf

Purpose Extreme value probability density function

Syntax $Y = \text{evpdf}(X, \mu, \sigma)$

Description $Y = \text{evpdf}(X, \mu, \sigma)$ returns the pdf of the type 1 extreme value distribution with location parameter μ and scale parameter σ , evaluated at the values in X . X , μ , and σ can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other inputs. The default values for μ and σ are 0 and 1, respectively.

The type 1 extreme value distribution is also known as the Gumbel distribution. The version used here is suitable for modeling minima; the mirror image of this distribution can be used to model maxima by negating X . See “Extreme Value Distribution” on page B-32 for more details. If x has a Weibull distribution, then $X = \log(x)$ has the type 1 extreme value distribution.

See Also pdf | evcdf | evinv | evstat | evfit | evlike | evrnd

How To • “Extreme Value Distribution” on page B-32

Purpose	Extreme value random numbers
Syntax	<pre>R = evrnd(mu,sigma) R = evrnd(mu,sigma,m,n,...) R = evrnd(mu,sigma,[m,n,...])</pre>
Description	<p><code>R = evrnd(mu,sigma)</code> generates random numbers from the extreme value distribution with parameters specified by location parameter <code>mu</code> and scale parameter <code>sigma</code>. <code>mu</code> and <code>sigma</code> can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of <code>R</code>. A scalar input for <code>mu</code> or <code>sigma</code> is expanded to a constant array with the same dimensions as the other input.</p> <p><code>R = evrnd(mu,sigma,m,n,...)</code> or <code>R = evrnd(mu,sigma,[m,n,...])</code> generates an <code>m-by-n-by-...</code> array containing random numbers from the extreme value distribution with parameters <code>mu</code> and <code>sigma</code>. <code>mu</code> and <code>sigma</code> can each be scalars or arrays of the same size as <code>R</code>.</p> <p>The type 1 extreme value distribution is also known as the Gumbel distribution. The version used here is suitable for modeling minima; the mirror image of this distribution can be used to model maxima by negating <code>R</code>. See “Extreme Value Distribution” on page B-32 for more details. If x has a Weibull distribution, then $X = \log(x)$ has the type 1 extreme value distribution.</p>
See Also	<code>random</code> <code>evpdf</code> <code>evcdf</code> <code>evinv</code> <code>evstat</code> <code>evfit</code> <code>evlike</code>
How To	<ul style="list-style-type: none">• “Extreme Value Distribution” on page B-32

evstat

Purpose Extreme value mean and variance

Syntax `[M,V] = evstat(mu,sigma)`

Description `[M,V] = evstat(mu,sigma)` returns the mean of and variance for the type 1 extreme value distribution with location parameter `mu` and scale parameter `sigma`. `mu` and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other input. The default values for `mu` and `sigma` are 0 and 1, respectively.

The type 1 extreme value distribution is also known as the Gumbel distribution. The version used here is suitable for modeling minima; the mirror image of this distribution can be used to model maxima. See “Extreme Value Distribution” on page B-32 for more details. If x has a Weibull distribution, then $X = \log(x)$ has the type 1 extreme value distribution.

See Also `evpdf` | `evcdf` | `evinv` | `evfit` | `evlike` | `evrnd`

How To

- “Extreme Value Distribution” on page B-32

Purpose Exponential cumulative distribution function

Syntax `P = expcdf(X,mu)`
`[P, PLO, PUP] = expcdf(X,mu,pcov,alpha)`

Description `P = expcdf(X,mu)` computes the exponential cdf at each of the values in `X` using the corresponding mean parameter `mu`. `X` and `mu` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input. The parameters in `mu` must be positive.

The exponential cdf is

$$p = F(x | u) = \int_0^x \frac{1}{\mu} e^{-\frac{t}{\mu}} dt = 1 - e^{-\frac{x}{\mu}}$$

The result, `p`, is the probability that a single observation from an exponential distribution will fall in the interval `[0 x]`.

`[P, PLO, PUP] = expcdf(X,mu,pcov,alpha)` produces confidence bounds for `P` when the input mean parameter `mu` is an estimate. `pcov` is the variance of the estimated `mu`. `alpha` specifies `100(1 - alpha)%` confidence bounds. The default value of `alpha` is `0.05`. `PLO` and `PUP` are arrays of the same size as `P` containing the lower and upper confidence bounds. The bounds are based on a normal approximation for the distribution of the log of the estimate of `mu`. If you estimate `mu` from a set of data, you can get a more accurate set of bounds by applying `expfit` to the data to get a confidence interval for `mu`, and then evaluating `expinv` at the lower and upper endpoints of that interval.

Examples The following code shows that the median of the exponential distribution is `*log(2)`.

```
mu = 10:10:60;
p = expcdf(log(2)*mu,mu)
p =
    0.5000    0.5000    0.5000    0.5000    0.5000    0.5000
```

expcdf

What is the probability that an exponential random variable is less than or equal to the mean, μ ?

```
mu = 1:6;  
x = mu;  
p = expcdf(x,mu)  
p =  
    0.6321    0.6321    0.6321    0.6321    0.6321    0.6321
```

See Also

[cdf](#) | [exppdf](#) | [expinv](#) | [expstat](#) | [expfit](#) | [explike](#) | [exprnd](#)

How To

- “Exponential Distribution” on page B-29

Purpose

Exponential parameter estimates

Syntax

```
muhat = expfit(data)
[muhat,muci] = expfit(data)
[muhat,muci] = expfit(data,alpha)
[...] = expfit(data,alpha,censoring)
[...] = expfit(data,alpha,censoring,freq)
```

Description

`muhat = expfit(data)` estimates the mean of an exponentially distributed sample data. Each entry of `muhat` corresponds to the data in a column of data.

`[muhat,muci] = expfit(data)` returns 95% confidence intervals for the mean parameter estimates in matrix `muci`. The first row of `muci` contains the lower bounds of the confidence intervals, and the second row contains the upper bounds.

`[muhat,muci] = expfit(data,alpha)` returns $100(1 - \alpha)\%$ confidence intervals for the parameter estimates, where `alpha` is a value in the range `[0 1]` specifying the width of the confidence intervals. By default, `alpha` is 0.05, which corresponds to 95% confidence intervals.

`[...] = expfit(data,alpha,censoring)` accepts a Boolean vector, `censoring`, of the same size as `data`, which is 1 for observations that are right-censored and 0 for observations that are observed exactly. `data` must be a vector in order to pass in the argument `censoring`.

`[...] = expfit(data,alpha,censoring,freq)` accepts a frequency vector, `freq` of the same size as `data`. Typically, `freq` contains integer frequencies for the corresponding elements in `data`, but can contain any nonnegative values. Pass in `[]` for `alpha`, `censoring`, or `freq` to use their default values.

Examples

The following estimates the mean μ of exponentially distributed data, and returns a 95% confidence interval for the estimate:

```
mu = 3;
data = exprnd(mu,100,1); % Simulated data
```

expfit

```
[muhat,muci] = expfit(data)
muhat =
    2.7511
muci =
    2.2826
    3.3813
```

See Also

mle | explike | exppdf | expcdf | expinv | expstat | exprnd

Superclasses NeighborSearcher

Purpose Nearest neighbors search using exhaustive search

Description An ExhaustiveSearcher object performs *k*NN (*k*-nearest neighbor) search using exhaustive search. Search objects store information about the data used, and the distance metric and parameters. The search performance for this object, compared with the KDTreeSearcher object, tends to be better for larger dimensions (10 or more) and worse for smaller dimensions. For more information on search objects, see “What Are Search Objects?” on page 13-17.

Construction `NS = ExhaustiveSearcher(X, 'Name', Value)` constructs an ExhaustiveSearcher object based on *X*, where rows of *X* correspond to observations and columns correspond to variables, using one or more optional name/value pairs. You can then use this object to find neighbors in *X* nearest to the query points.

`NS = createns(X, 'NSMethod', 'exhaustive', 'Name', Value)` creates an ExhaustiveSearcher object based on *X* using `createns`, where rows of *X* correspond to observations and columns correspond to variables, using one or more optional name/value pairs. You can use this object to find neighbors in *X* nearest to the query points.

Name-Value Pair Arguments

Both the ExhaustiveSearcher and the createns functions accept one or more of the following optional name/value pairs as input:

Distance

A string or function handle specifying the default distance metric used when you call the knnsearch method.

- 'euclidean' — Euclidean distance (default).
- 'seuclidean' — Standardized Euclidean distance. Each coordinate difference between rows in *X* and the query matrix is scaled by dividing by the corresponding element of the standard

ExhaustiveSearcher

deviation computed from X , $S = \text{nanstd}(X)$. To specify another value for S , use the `Scale` argument.

- `'cityblock'` — City block distance.
- `'chebychev'` — Chebychev distance (maximum coordinate difference).
- `'minkowski'` — Minkowski distance.
- `'mahalanobis'` — Mahalanobis distance, computed using a positive definite covariance matrix C . The default value of C is $\text{nancov}(X)$. To change the value of C , use the `Cov` parameter.
- `'cosine'` — One minus the cosine of the included angle between observations (treated as vectors).
- `'correlation'` — One minus the sample linear correlation between observations (treated as sequences of values).
- `'spearman'` — One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
- `'hamming'` — Hamming distance, percentage of coordinates that differ.
- `'jaccard'` — One minus the Jaccard coefficient, the percentage of nonzero coordinates that differ.
- custom distance function — A distance function specified using `@` (for example, `@distfun`). A distance function must be of the form `function D2 = distfun(ZI, ZJ)`, taking as arguments a 1-by- n vector ZI containing a single row from X or from the query points Y , an $m2$ -by- n matrix ZJ containing multiple rows of X or Y , and returning an $m2$ -by-1 vector of distances $D2$, whose j th element is the distance between the observations ZI and $ZJ(j,:)$.

For more information on these distance metrics, see “Distance Metrics” on page 13-9.

P

A positive scalar indicating the exponent of Minkowski distance. This parameter is only valid when `Distance` is 'minkowski'. Default is 2.

Cov

A positive definite matrix indicating the covariance matrix when computing the Mahalanobis distance. This parameter is only valid when `Distance` is 'mahalanobis'. Default is `nancov(X)`.

Scale

A vector `S` with the length equal to the number of columns in `X`. Each coordinate of `X` and each query point is scaled by the corresponding element of `S` when computing the standardized Euclidean distance. This parameter is only valid when `Distance` is 'seuclidean'. Default is `nanstd(X)`.

Properties

X

A matrix used to create the object

Distance

A string specifying a built-in distance metric or a function handle that you provide when you create the object. This property is the default distance metric used when you call the `knnsearch` method to find nearest neighbors for future query points.

DistParameter

Specifies the additional parameter for the chosen distance metric. The value is:

- If 'Distance' is 'minkowski': A positive scalar indicating the exponent of the Minkowski distance.
- If 'Distance' is 'mahalanobis': A positive definite matrix representing the covariance matrix used for computing the Mahalanobis distance.

ExhaustiveSearcher

- If 'Distance' is 'seuclidean': A vector representing the scale value of the data when computing the 'seuclidean' distance.
- Otherwise: Empty.

Methods

knnsearch	Find k -nearest neighbors using ExhaustiveSearcher object
rangesearch	Find all neighbors within specified distance using object

Examples

Create an ExhaustiveSearcher object using the constructor:

```
load fisheriris
x = meas(:,3:4);
NS = ExhaustiveSearcher(x,'distance','minkowski')

NS =

    ExhaustiveSearcher

    Properties:
        X: [150x2 double]
        Distance: 'minkowski'
        DistParameter: 2
```

Create an ExhaustiveSearcher object using createns:

```
load fisheriris
x = meas(:,3:4);
NS = createns(x,'NsMethod','exhaustive',...
             'distance','minkowski')
```

NS =

ExhaustiveSearcher

Properties:

 X: [150x2 double]
 Distance: 'minkowski'
 DistParameter: 2

For more in-depth examples using the `knnsearch` method, see the method reference page or see “Example: Classifying Query Data Using `knnsearch`” on page 13-18.

References

[1] Friedman, J. H., Bentley, J. and Finkel, R. A. (1977). *An Algorithm for Finding Best Matches in Logarithmic Expected Time*, ACM Transactions on Mathematical Software 3, 209.

See Also

[createns](#) | [KDTreeSearcher](#) | [NeighborSearcher](#)

How To

- “*k*-Nearest Neighbor Search and Radius Search” on page 13-12
- “Distance Metrics” on page 13-9

expinv

Purpose Exponential inverse cumulative distribution function

Syntax
`X = expinv(P,mu)`
`[X,XLO,XUP] = expinv(X,mu,pcov,alpha)`

Description `X = expinv(P,mu)` computes the inverse of the exponential cdf with parameters specified by mean parameter `mu` for the corresponding probabilities in `P`. `P` and `mu` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input. The parameters in `mu` must be positive and the values in `P` must lie on the interval `[0 1]`.

`[X,XLO,XUP] = expinv(X,mu,pcov,alpha)` produces confidence bounds for `X` when the input mean parameter `mu` is an estimate. `pcov` is the variance of the estimated `mu`. `alpha` specifies `100(1 - alpha)%` confidence bounds. The default value of `alpha` is `0.05`. `XLO` and `XUP` are arrays of the same size as `X` containing the lower and upper confidence bounds. The bounds are based on a normal approximation for the distribution of the log of the estimate of `mu`. If you estimate `mu` from a set of data, you can get a more accurate set of bounds by applying `expfit` to the data to get a confidence interval for `mu`, and then evaluating `expinv` at the lower and upper end points of that interval.

The inverse of the exponential cdf is

$$x = F^{-1}(p | \mu) = -\mu \ln(1 - p)$$

The result, `x`, is the value such that an observation from an exponential distribution with parameter `μ` will fall in the range `[0 x]` with probability `p`.

Examples Let the lifetime of light bulbs be exponentially distributed with `μ = 700` hours. What is the median lifetime of a bulb?

```
expinv(0.50,700)
ans =
```


485.2030

Suppose you buy a box of “700 hour” light bulbs. If 700 hours is the mean life of the bulbs, half of them will burn out in less than 500 hours.

See Also

`icdf` | `expcdf` | `exppdf` | `expstat` | `expfit` | `explike` | `expnrd`

How To

- “Exponential Distribution” on page B-29

explike

Purpose Exponential negative log-likelihood

Syntax
`nlogL = explike(param,data)`
`[nlogL,avar] = explike(param,data)`
`[...] = explike(param,data,censoring)`
`[...] = explike(param,data,censoring,freq)`

Description `nlogL = explike(param,data)` returns the negative of the log-likelihood for the exponential distribution. `param` is the mean parameter, `mu`. `nlogL` is a scalar.

`[nlogL,avar] = explike(param,data)` returns the inverse of Fisher's information, `avar`, a scalar. If the input parameter value in `param` is the maximum likelihood estimate, `avar` is its asymptotic variance. `avar` is based on the observed Fisher's information, not the expected information.

`[...] = explike(param,data,censoring)` accepts a Boolean vector, `censoring`, of the same size as `data`, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.

`[...] = explike(param,data,censoring,freq)` accepts a frequency vector, `freq`, of the same size as `data`. The vector `freq` typically contains integer frequencies for the corresponding elements in `data`, but can contain any nonnegative values. Pass in `[]` for `censoring` to use its default value.

See Also `expcdf` | `exppdf` | `expstat` | `expfit` | `expinv` | `exprnd`

How To • “Exponential Distribution” on page B-29

Purpose Write dataset array to file

Syntax

```
export(DS, 'file', filename)
export(DS)
export(DS, 'file', filename, 'Delimiter', delim)
export(DS, 'XLSfile', filename)
export(DS, 'XPTfile', filename)
export(DS, ..., 'WriteVarNames', false)
export(DS, ..., 'WriteObsNames', false)
```

Description `export(DS, 'file', filename)` writes the dataset array DS to a tab-delimited text file, including variable names and observation names, if present. If the observation names exist, the name in the first column of the first line of the file is the first dimension name for the dataset (by default, 'Observations'). `export` overwrites any existing file named filename.

`export(DS)` writes to a text file whose default name is the name of the dataset array DS appended by '.txt'. If `export` cannot construct the file name from the dataset array input, it writes to the file 'dataset.txt'. `export` overwrites any existing file.

`export(DS, 'file', filename, 'Delimiter', delim)` writes the dataset array DS to a text file using the delimiter `delim`. `delim` must be one of the following:

- ' ' or 'space'
- '\t' or 'tab'
- ',' or 'comma'
- ';' or 'semi'
- '|' or 'bar'

`export(DS, 'XLSfile', filename)` writes the dataset array DS to a Microsoft® Excel spreadsheet file, including variable names and observation names (if present). You can specify the 'Sheet' and

dataset.export

'Range' parameter name/value pairs, with parameter values as accepted by the `xlsread` function.

`export(DS, 'XPTFile', filename)` writes the dataset array `DS` to a SAS XPORT format file. When writing to an XPORT format file, variables must be scalar valued. `export` saves observation names to a variable called `obsnames`, unless the `WriteObsNames` parameter described below is `false`. The XPORT format restricts the length of variable names to eight characters; longer variable names are truncated.

`export(DS, ..., 'WriteVarNames', false)` does not write the variable names to the text file. `export(DS, ..., 'WriteVarNames', true)` is the default, writing the names as column headings in the first line of the file.

`export(DS, ..., 'WriteObsNames', false)` does not write the observation names to the text file. `export(DS, ..., 'WriteObsNames', true)` is the default, writing the names as the first column of the file.

In some cases, `export` creates a text file that does not represent `A` exactly, as described below. If you use `dataset` to read the file back into MATLAB, the new dataset array may not have exactly the same contents as the original dataset array. Save `A` as a MAT-file if you need to import it again as a dataset array.

`export` writes out numeric variables using long `g` format, and categorical or character variables as unquoted strings.

For non-character variables with more than one column, `export` writes out multiple delimiter-separated fields on each line, and constructs suitable column headings for the first line of the file.

`export` writes out variables that have more than two dimensions as a single empty field in each line of the file.

For cell-valued variables, `export` writes out the contents of each cell only when the cell contains a single row, and writes out a single empty field otherwise.

In some cases, `export` creates a file that cannot be read back into MATLAB using `dataset`. Writing a dataset array that contains a cell-valued variable whose cell contents are not scalars results in a mismatch in the file between the number of fields on each line and the number of column headings on the first line. Writing a dataset array that contains a cell-valued variable whose cell contents are not all the same length results in a different number of fields on each line in the file. Therefore, if you might need to import a dataset array again, save it as a `.mat` file.

Examples

Move data between external text files and dataset arrays in the MATLAB workspace:

```
A = dataset('file','sat2.dat','delimiter',' ','')
A =
    Test          Gender          Score
    'Verbal'      'Male'          470
    'Verbal'      'Female'        530
    'Quantitative' 'Male'          520
    'Quantitative' 'Female'        480

export(A(A.Score > 500,:), 'file', 'HighScores.txt')

B = dataset('file', 'HighScores.txt', 'delimiter', '\t')
B =
    Test          Gender          Score
    'Verbal'      'Female'        530
    'Quantitative' 'Male'          520
```

See Also

`dataset`

exp pdf

Purpose Exponential probability density function

Syntax `Y = exp pdf (X, mu)`

Description `Y = exp pdf (X, mu)` returns the pdf of the exponential distribution with mean parameter `mu`, evaluated at the values in `X`. `X` and `mu` can be vectors, matrices, or multidimensional arrays that have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input. The parameters in `mu` must be positive.

The exponential pdf is

$$y = f(x | \mu) = \frac{1}{\mu} e^{-\frac{x}{\mu}}$$

The exponential pdf is the gamma pdf with its first parameter equal to 1.

The exponential distribution is appropriate for modeling waiting times when the probability of waiting an additional period of time is independent of how long you have already waited. For example, the probability that a light bulb will burn out in its next minute of use is relatively independent of how many minutes it has already burned.

Examples

```
y = exp pdf (5, 1:5)
y =
    0.0067    0.0410    0.0630    0.0716    0.0736
```

```
y = exp pdf (1:5, 1:5)
y =
    0.3679    0.1839    0.1226    0.0920    0.0736
```

See Also `pdf` | `expcdf` | `expinv` | `expstat` | `expfit` | `explike` | `expnrd`

How To • “Exponential Distribution” on page B-29

Purpose Exponential random numbers

Syntax
 R = exprnd(mu)
 R = exprnd(mu,m,n,...)
 R = exprnd(mu,[m,n,...])

Description R = exprnd(mu) generates random numbers from the exponential distribution with mean parameter mu. mu can be a vector, a matrix, or a multidimensional array. The size of R is the size of mu.
 R = exprnd(mu,m,n,...) or R = exprnd(mu,[m,n,...]) generates an m-by-n-by-... array containing random numbers from the exponential distribution with mean parameter mu. mu can be a scalar or an array of the same size as R.

Examples

```
n1 = exprnd(5:10)
n1 =
    7.5943    18.3400    2.7113    3.0936    0.6078    9.5841

n2 = exprnd(5:10,[1 6])
n2 =
    3.2752    1.1110    23.5530    23.4303    5.7190    3.9876

n3 = exprnd(5,2,3)
n3 =
    24.3339    13.5271    1.8788
     4.7932     4.3675    2.6468
```

See Also random | expcdf | exppdf | expstat | expfit | explike | expinv

How To • “Exponential Distribution” on page B-29

expstat

Purpose Exponential mean and variance

Syntax `[m,v] = expstat(mu)`

Description `[m,v] = expstat(mu)` returns the mean of and variance for the exponential distribution with parameters `mu`. `mu` can be a vectors, matrix, or multidimensional array. The mean of the exponential distribution is μ , and the variance is μ^2 .

Examples

```
[m,v] = expstat([1 10 100 1000])  
m =  
    1    10    100    1000  
v =  
    1    100   10000  1000000
```

See Also `expinv` | `expcdf` | `exppdf` | `expstat` | `expfit` | `explike` | `exprnd`

How To

- “Exponential Distribution” on page B-29

Purpose

Factor analysis

Syntax

```
lambda = factoran(X,m)
[lambda,psi] = factoran(X,m)
[lambda,psi,T] = factoran(X,m)
[lambda,psi,T,stats] = factoran(X,m)
[lambda,psi,T,stats,F] = factoran(X,m)
[...] = factoran(...,param1,val1,param2,val2,...)
```

Definitions

factoran computes the maximum likelihood estimate (MLE) of the factor loadings matrix Λ in the factor analysis model

$$x = \mu + \Lambda f + e$$

where x is a vector of observed variables, μ is a constant vector of means, Λ is a constant d -by- m matrix of factor loadings, f is a vector of independent, standardized common factors, and e is a vector of independent specific factors. x , μ , and e are of length d . f is of length m .

Alternatively, the factor analysis model can be specified as

$$\text{cov}(x) = \Lambda\Lambda^T + \Psi$$

where $\Psi = \text{cov}(e)$ is a d -by- d diagonal matrix of specific variances.

Description

lambda = factoran(X,m) returns the maximum likelihood estimate, lambda, of the factor loadings matrix, in a common factor analysis model with m common factors. X is an n -by- d matrix where each row is an observation of d variables. The (i, j) th element of the d -by- m matrix lambda is the coefficient, or loading, of the j th factor for the i th variable. By default, factoran calls the function rotatefactors to rotate the estimated factor loadings using the 'varimax' option.

[lambda,psi] = factoran(X,m) also returns maximum likelihood estimates of the specific variances as a column vector psi of length d .

[lambda,psi,T] = factoran(X,m) also returns the m -by- m factor loadings rotation matrix T .

factoran

`[lambda,psi,T,stats] = factoran(X,m)` also returns a structure `stats` containing information relating to the null hypothesis, H_0 , that the number of common factors is m . `stats` includes the following fields:

Field	Description
<code>loglike</code>	Maximized log-likelihood value
<code>dfe</code>	Error degrees of freedom = $((d-m)^2 - (d+m))/2$
<code>chisq</code>	Approximate chi-squared statistic for the null hypothesis
<code>p</code>	Right-tail significance level for the null hypothesis

`factoran` does not compute the `chisq` and `p` fields unless `dfe` is positive and all the specific variance estimates in `psi` are positive (see “Heywood Case” on page 20-630 below). If X is a covariance matrix, then you must also specify the `'nobs'` parameter if you want `factoran` to compute the `chisq` and `p` fields.

`[lambda,psi,T,stats,F] = factoran(X,m)` also returns, in `F`, predictions of the common factors, known as factor scores. `F` is an n -by- m matrix where each row is a prediction of m common factors. If X is a covariance matrix, `factoran` cannot compute `F`. `factoran` rotates `F` using the same criterion as for `lambda`.

`[...] = factoran(...,param1,val1,param2,val2,...)` enables you to specify optional parameter name/value pairs to control the model fit and the outputs. The following are the valid parameter/value pairs.

Parameter	Value	
<code>'xtype'</code>	Type of input in the matrix X . <code>'xtype'</code> can be one of:	
	<code>'data'</code>	Raw data (default)
	<code>'covariance'</code>	Positive definite covariance or correlation matrix

Parameter	Value	
'scores'	Method for predicting factor scores. 'scores' is ignored if X is not raw data.	
	'wls' 'Bartlett'	Synonyms for a weighted least-squares estimate that treats F as fixed (default)
	'regression' 'Thomson'	Synonyms for a minimum mean squared error prediction that is equivalent to a ridge regression
'start'	Starting point for the specific variances psi in the maximum likelihood optimization. Can be specified as:	
	'random'	Chooses d uniformly distributed values on the interval [0,1].
	'Rsquared'	Chooses the starting vector as a scale factor times $\text{diag}(\text{inv}(\text{corrcoef}(X)))$ (default). For examples, see Jöreskog [2].
	Positive integer	Performs the given number of maximum likelihood fits, each initialized as with 'random'. factoran returns the fit with the highest likelihood.
	Matrix	Performs one maximum likelihood fit for each column of the specified matrix. The ith optimization is initialized with the values from the ith column. The matrix must have d rows.

factoran

Parameter	Value
'rotate'	Method used to rotate factor loadings and scores. 'rotate' can have the same values as the 'Method' parameter of rotatefactors. See the reference page for rotatefactors for a full description of the available methods.
	'none' Performs no rotation.
	'equamax' Special case of the orthomax rotation. Use the 'normalize', 'reltol', and 'maxit' parameters to control the details of the rotation.
	'orthomax' Orthogonal rotation that maximizes a criterion based on the variance of the loadings. Use the 'coeff', 'normalize', 'reltol', and 'maxit' parameters to control the details of the rotation.
	'parsimax' Special case of the orthomax rotation (default). Use the 'normalize', 'reltol', and 'maxit' parameters to control the details of the rotation.
	'pattern' Performs either an oblique rotation (the default) or an orthogonal rotation to best match a specified pattern matrix. Use the 'type' parameter to choose the type of rotation. Use the 'target' parameter to specify the pattern matrix.

Parameter	Value	
	'procrustes'	<p>Performs either an oblique (the default) or an orthogonal rotation to best match a specified target matrix in the least squares sense.</p> <p>Use the 'type' parameter to choose the type of rotation. Use 'target' to specify the target matrix.</p>
	'promax'	<p>Performs an oblique procrustes rotation to a target matrix determined by factoran as a function of an orthomax solution.</p> <p>Use the 'power' parameter to specify the exponent for creating the target matrix. Because 'promax' uses 'orthomax' internally, you can also specify the parameters that apply to 'orthomax'.</p>
	'quartimax'	<p>Special case of the orthomax rotation (default). Use the 'normalize', 'reltol', and 'maxit' parameters to control the details of the rotation.</p>
	'varimax'	<p>Special case of the orthomax rotation (default). Use the 'normalize', 'reltol', and 'maxit' parameters to control the details of the rotation.</p>

Parameter	Value
	<p>Function</p> <p>Function handle to rotation function of the form</p> $[B, T] = \text{myrotation}(A, \dots)$ <p>where A is a d-by-m matrix of unrotated factor loadings, B is a d-by-m matrix of rotated loadings, and T is the corresponding m-by-m rotation matrix.</p> <p>Use the <code>factoran</code> parameter <code>'userargs'</code> to pass additional arguments to this rotation function. See “Example 4” on page 20-635.</p>
<code>'coeff'</code>	Coefficient, often denoted as γ , defining the specific <code>'orthomax'</code> criterion. Must be from 0 to 1. The value 0 corresponds to <code>quartimax</code> , and 1 corresponds to <code>varimax</code> . Default is 1.
<code>'normalize'</code>	Flag indicating whether the loading matrix should be row-normalized (1) or left unnormalized (0) for <code>'orthomax'</code> or <code>'varimax'</code> rotation. Default is 1.
<code>'reltol'</code>	Relative convergence tolerance for <code>'orthomax'</code> or <code>'varimax'</code> rotation. Default is <code>sqrt(eps)</code> .
<code>'maxit'</code>	Iteration limit for <code>'orthomax'</code> or <code>'varimax'</code> rotation. Default is 250.
<code>'target'</code>	Target factor loading matrix for <code>'procrustes'</code> rotation. Required for <code>'procrustes'</code> rotation. No default value.
<code>'type'</code>	Type of <code>'procrustes'</code> rotation. Can be <code>'oblique'</code> (default) or <code>'orthogonal'</code> .

Parameter	Value
'power'	Exponent for creating the target matrix in the 'promax' rotation. Must be ≥ 1 . Default is 4.
'userargs'	Denotes the beginning of additional input values for a user-defined rotation function. <code>factoran</code> appends all subsequent values, in order and without processing, to the rotation function argument list, following the unrotated factor loadings matrix A. See “Example 4” on page 20-635.
'nobs'	If X is a covariance or correlation matrix, indicates the number of observations that were used in its estimation. This allows calculation of significance for the null hypothesis even when the original data are not available. There is no default. 'nobs' is ignored if X is raw data.
'delta'	Lower bound for the specific variances ψ_i during the maximum likelihood optimization. Default is 0.005.
'optimopts'	Structure that specifies control parameters for the iterative algorithm the function uses to compute maximum likelihood estimates. Create this structure with the function <code>statset</code> . Enter <code>statset('factoran')</code> to see the names and default values of the parameters that <code>factoran</code> accepts in the options structure. See the reference page for <code>statset</code> for more information about these options.

Tips

Observed Data Variables

The variables in the observed data matrix X must be linearly independent, i.e., $\text{cov}(X)$ must have full rank, for maximum likelihood estimation to succeed. `factoran` reduces both raw data and a covariance matrix to a correlation matrix before performing the fit.

`factoran` standardizes the observed data X to zero mean and unit variance before estimating the loadings λ . This does not affect the model fit, because MLEs in this model are invariant to scale. However, λ and ψ are returned in terms of the standardized variables, i.e., $\lambda\lambda' + \text{diag}(\psi)$ is an estimate of the correlation matrix of the original data X (although not after an oblique rotation). See “Example 1” on page 20-630 and “Example 3” on page 20-632.

Heywood Case

If elements of ψ are equal to the value of the `'delta'` parameter (i.e., they are essentially zero), the fit is known as a Heywood case, and interpretation of the resulting estimates is problematic. In particular, there can be multiple local maxima of the likelihood, each with different estimates of the loadings and the specific variances. Heywood cases can indicate overfitting (i.e., m is too large), but can also be the result of underfitting.

Rotation of Factor Loadings and Scores

Unless you explicitly specify no rotation using the `'rotate'` parameter, `factoran` rotates the estimated factor loadings, λ , and the factor scores, F . The output matrix T is used to rotate the loadings, i.e., $\lambda = \lambda_0 T$, where λ_0 is the initial (unrotated) MLE of the loadings. T is an orthogonal matrix for orthogonal rotations, and the identity matrix for no rotation. The inverse of T is known as the primary axis rotation matrix, while T itself is related to the reference axis rotation matrix. For orthogonal rotations, the two are identical.

`factoran` computes factor scores that have been rotated by $\text{inv}(T')$, i.e., $F = F_0 * \text{inv}(T')$, where F_0 contains the unrotated predictions. The estimated covariance of F is $\text{inv}(T' * T)$, which, for orthogonal or no rotation, is the identity matrix. Rotation of factor loadings and scores is an attempt to create a more easily interpretable structure in the loadings matrix after maximum likelihood estimation.

Examples

Example 1

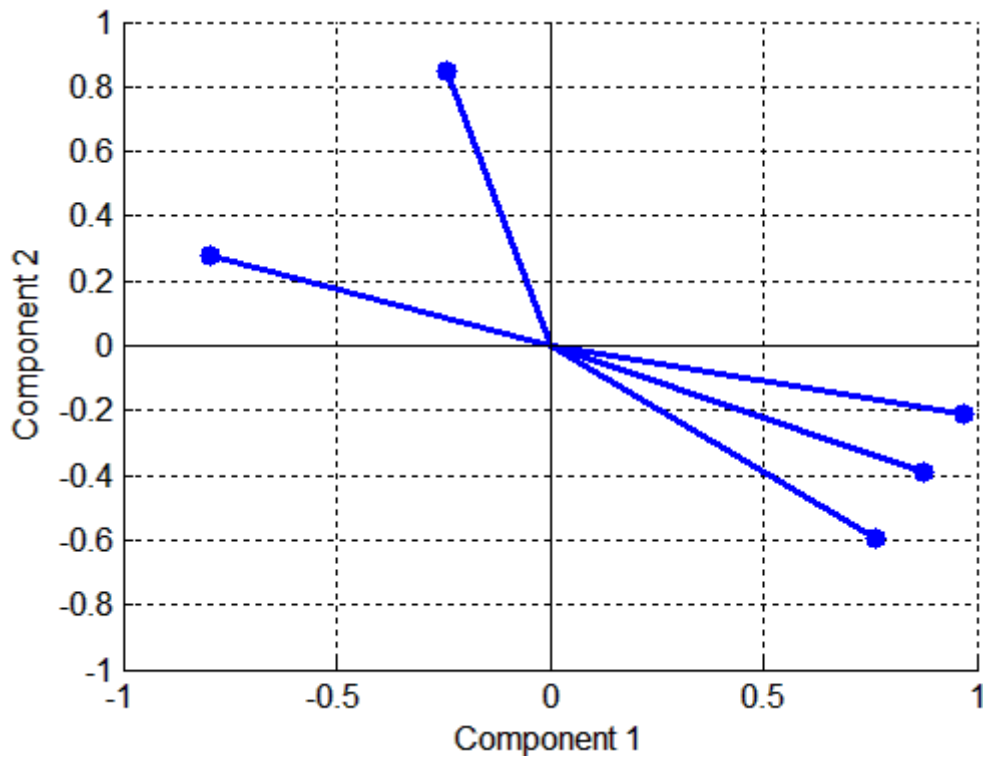
Load the `carbig` data, and fit the default model with two factors.


```
load carbig

X = [Acceleration Displacement Horsepower MPG Weight];
X = X(all(~isnan(X),2),:);
[Lambda,Psi,T,stats,F] = factoran(X,2,...
    'scores','regression');
inv(T'*T) % Estimated correlation matrix of F, == eye(2)
Lambda*Lambda'+diag(Psi) % Estimated correlation matrix
Lambda*inv(T) % Unrotate the loadings
F*T' % Unrotate the factor scores

biplot(Lambda,... % Create biplot of two factors
    'LineWidth',2,...
    'MarkerSize',20)
```

factoran



Example 2

Although the estimates are the same, the use of a covariance matrix rather than raw data doesn't let you request scores or significance level:

```
[Lambda,Psi,T] = factoran(cov(X),2,'xtype','cov')  
[Lambda,Psi,T] = factoran(corrcoef(X),2,'xtype','cov')
```

Example 3

Use promax rotation:

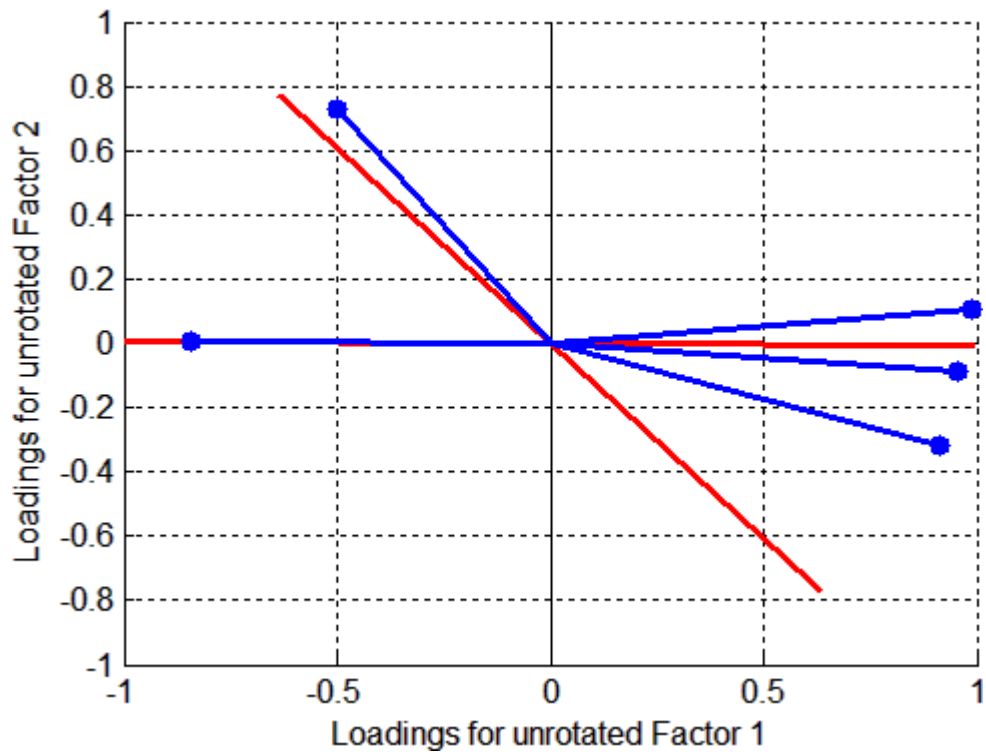
```
[Lambda,Psi,T,stats,F] = factoran(X,2,'rotate','promax',...  
                                'powerpm',4);
```

```
inv(T'*T) % Est'd corr of F,  
% no longer eye(2)  
Lambda*inv(T'*T)*Lambda'+diag(Psi) % Est'd corr of X
```

Plot the unrotated variables with oblique axes superimposed.

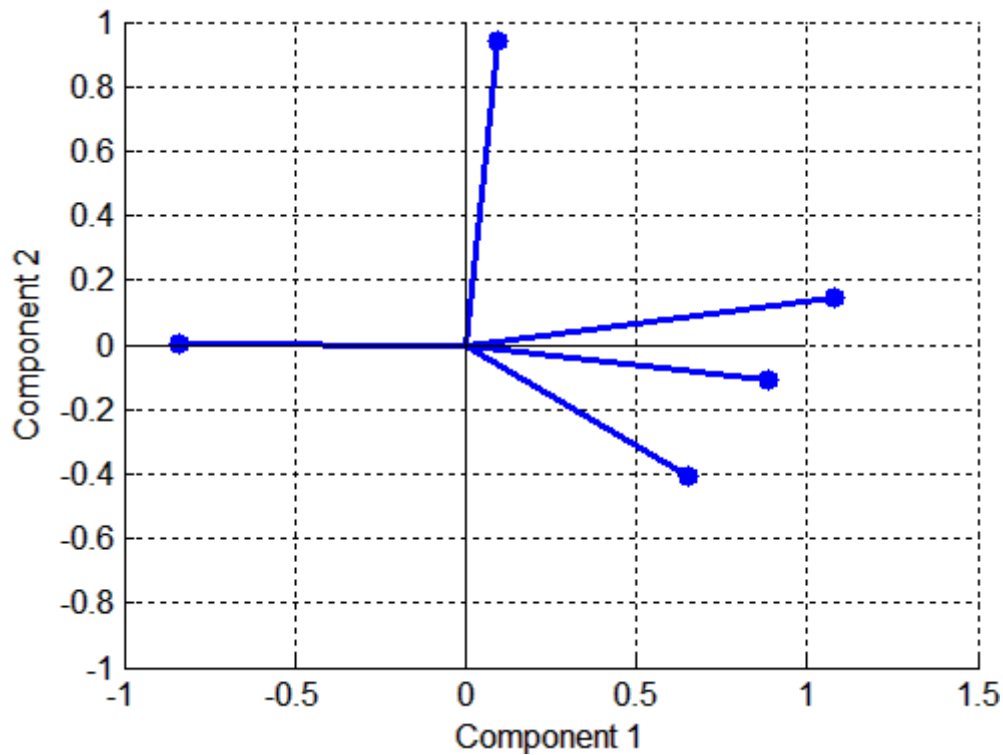
```
invT = inv(T)  
Lambda0 = Lambda*invT  
  
line([-invT(1,1) invT(1,1) NaN -invT(2,1) invT(2,1)], ...  
      [-invT(1,2) invT(1,2) NaN -invT(2,2) invT(2,2)], ...  
      'Color','r','linewidth',2)  
hold on  
biplot(Lambda0,...  
       'LineWidth',2,...  
       'MarkerSize',20)  
xlabel('Loadings for unrotated Factor 1')  
ylabel('Loadings for unrotated Factor 2')
```

factoran



Plot the rotated variables against the oblique axes:

```
biplot(Lambda, 'LineWidth', 2, 'MarkerSize', 20)
```



Example 4

Syntax for passing additional arguments to a user-defined rotation function:

```
[Lambda,Psi,T] = ...
    factoran(X,2,'rotate',@myrotation,'userargs',1,'two');
```

References

- [1] Harman, H. H. *Modern Factor Analysis*. 3rd Ed. Chicago: University of Chicago Press, 1976.
- [2] Jöreskog, K. G. "Some Contributions to Maximum Likelihood Factor Analysis." *Psychometrika*. Vol. 32, Issue 4, 1967, pp. 443–482.

factoran

[3] Lawley, D. N., and A. E. Maxwell. *Factor Analysis as a Statistical Method*. 2nd Ed. New York: American Elsevier Publishing Co., 1971.

See Also

[biplot](#) | [pca](#) | [procrustes](#) | [pcacov](#) | [rotatefactors](#) | [statset](#)

Purpose Fraction of in-bag observations

Description The FBoot property is the fraction of observations to be randomly selected with replacement for each bootstrap replica. The size of each replica is given by $n \cdot \text{FBoot}$, where n is the number of observations in the training set. The default value is 1.

fcdf

Purpose F cumulative distribution function

Syntax $P = \text{fcdf}(X, V1, V2)$

Description $P = \text{fcdf}(X, V1, V2)$ computes the F cdf at each of the values in X using the corresponding numerator degrees of freedom $V1$ and denominator degrees of freedom $V2$. X , $V1$, and $V2$ can be vectors, matrices, or multidimensional arrays that are all the same size. A scalar input is expanded to a constant matrix with the same dimensions as the other inputs. $V1$ and $V2$ parameters must contain real positive values.

The F cdf is

$$p = F(x | v_1, v_2) = \int_0^x \frac{\Gamma\left[\frac{(v_1 + v_2)}{2}\right]}{\Gamma\left(\frac{v_1}{2}\right)\Gamma\left(\frac{v_2}{2}\right)} \left(\frac{v_1}{v_2}\right)^{\frac{v_1}{2}} \frac{t^{\frac{v_1-2}{2}}}{\left[1 + \left(\frac{v_1}{v_2}\right)t\right]^{\frac{v_1+v_2}{2}}} dt$$

The result, p , is the probability that a single observation from an F distribution with parameters v_1 and v_2 will fall in the interval $[0, x]$.

Examples

The following illustrates a useful mathematical identity for the F distribution:

```
nu1 = 1:5;  
nu2 = 6:10;  
x = 2:6;
```

```
F1 = fcdf(x, nu1, nu2)  
F1 =  
    0.7930    0.8854    0.9481    0.9788    0.9919
```

```
F2 = 1 - fcdf(1./x, nu2, nu1)  
F2 =  
    0.7930    0.8854    0.9481    0.9788    0.9919
```


See Also

[cdf](#) | [fpdf](#) | [finv](#) | [fstat](#) | [frnd](#)

How To

- “F Distribution” on page B-38

GeneralizedLinearModel.feval

Purpose Evaluate generalized linear regression model prediction

Syntax `ypred = feval mdl, Xnew(1), Xnew(2), ..., Xnew(n)`

Description `ypred = feval(mdl, Xnew(1), Xnew(2), ..., Xnew(n))` returns the predicted response of `mdl` to the input `[Xnew(1), Xnew(2), ..., Xnew(n)]`.

Tips

- `feval` allows you to easily evaluate predictions of a model when the model was fitted using a dataset array. `predict` requires a dataset array with the same predictor names, but you can use simple arrays of scalars with `feval`.

Input Arguments

mdl

Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

Xnew

Predictor component. `Xnew(i)` can be one of:

- Scalar
- Vector
- Array

Each nonscalar component must have the same size (number of elements in each dimension).

If you pass just one `Xnew` array, `Xnew` can be a dataset array or an array of doubles, where each column of the array represents one predictor.

Output Arguments

ypred

Predicted mean values at `Xnew`. `ypred` is the same size as each component of `Xnew`.

For binomial models, `feval` uses 1 as the `BinomialSize` parameter, so `ypred` is predicted probabilities.

For models with an offset, `feval` uses 0 as the offset value.

Examples

Predict Responses Using `feval`

Generate a generalized linear model, and plot its responses to a range of input data.

Generate artificial data for the model, Poisson random numbers with two underlying predictors $X(1)$ and $X(2)$.

```
rng('default') % for reproducibility
rndvars = randn(100,2);
X = [2+rndvars(:,1),rndvars(:,2)];
mu = exp(1 + X*[1;2]);
y = poissrnd(mu);
```

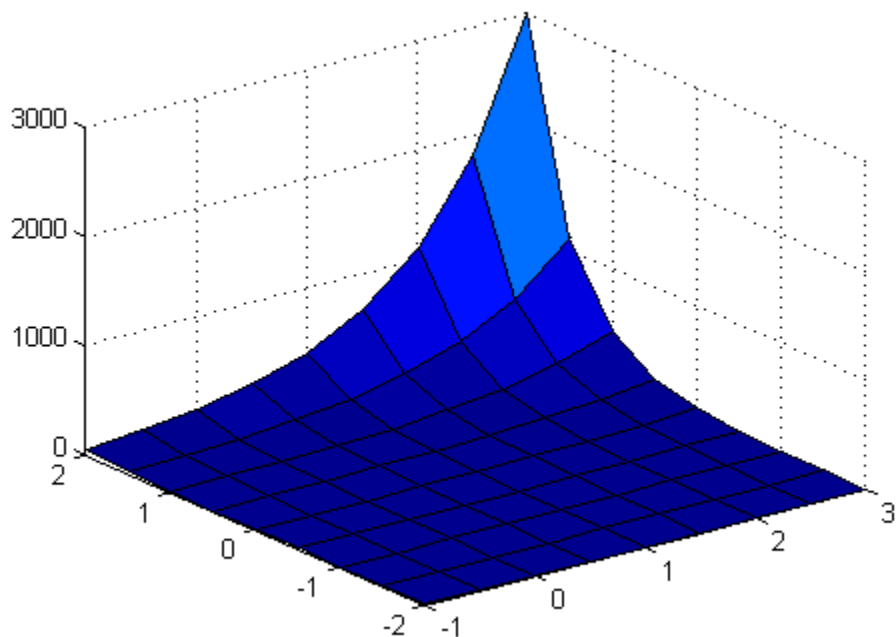
Create a generalized linear regression model of Poisson data.

```
mdl = GeneralizedLinearModel.fit(X,y,...
    'y ~ x1 + x2','distr','poisson');
```

Generate a range of values for $X(1)$ and $X(2)$, and plot the model predictions at those values.

```
[Xtest1 Xtest2] = meshgrid(-1:.5:3,-2:.5:2);
Z = feval(mdl,Xtest1,Xtest2);
surf(Xtest1,Xtest2,Z)
```

GeneralizedLinearModel.feval



Alternatives

`predict` gives the same predictions, but uses a single input array with one observation in each row, rather than one component in each input argument.

`random` predicts with added noise.

See Also

`GeneralizedLinearModel` | `predict` | `random` |

Related Examples

- “feval” on page 9-167

Concepts

- “Generalized Linear Models” on page 9-141

Purpose	Evaluate linear regression model prediction
Syntax	<code>ypred = feval(md1,Xnew(1),Xnew(2),...,Xnew(n))</code>
Description	<code>ypred = feval(md1,Xnew(1),Xnew(2),...,Xnew(n))</code> returns the predicted response of <code>md1</code> to the input <code>[Xnew(1),Xnew(2),...,Xnew(n)]</code> .
Input Arguments	<p>md1</p> <p>Linear model, as constructed by <code>LinearModel.fit</code> or <code>LinearModel.stepwise</code>.</p> <p>Xnew</p> <p>Predictor component. <code>Xnew(i)</code> can be one of:</p> <ul style="list-style-type: none">• Scalar• Vector• Array <p>Each nonscalar component must have the same size (number of elements in each dimension).</p> <p>If you pass just one <code>Xnew</code> array, <code>Xnew</code> can be a dataset array or an array of doubles, where each column of the array represents one predictor.</p>
Output Arguments	<p>ypred</p> <p>Predicted mean values at <code>Xnew</code>. <code>ypred</code> is the same size as each component of <code>Xnew</code>.</p> <p>For models with an offset, <code>feval</code> uses 0 as the offset value.</p>
Examples	<p>Plot Different Categorical Levels</p> <p>Fit a mileage model to the <code>smallcar</code> data, including the <code>Year</code> categorical predictor. Superimpose fitted curves on a scatter plot of the data.</p>

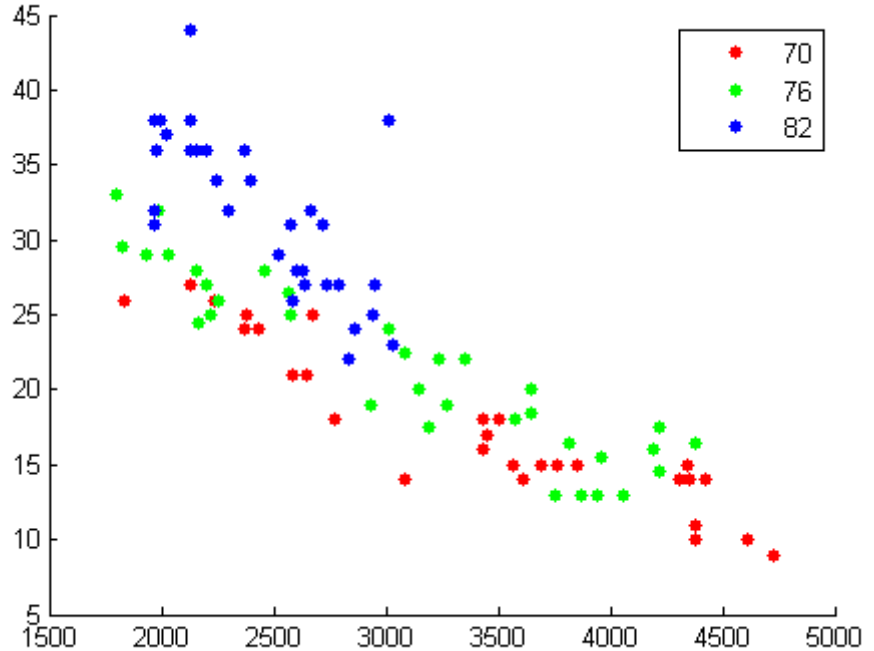
LinearModel.feval

Load the data and fit a model.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

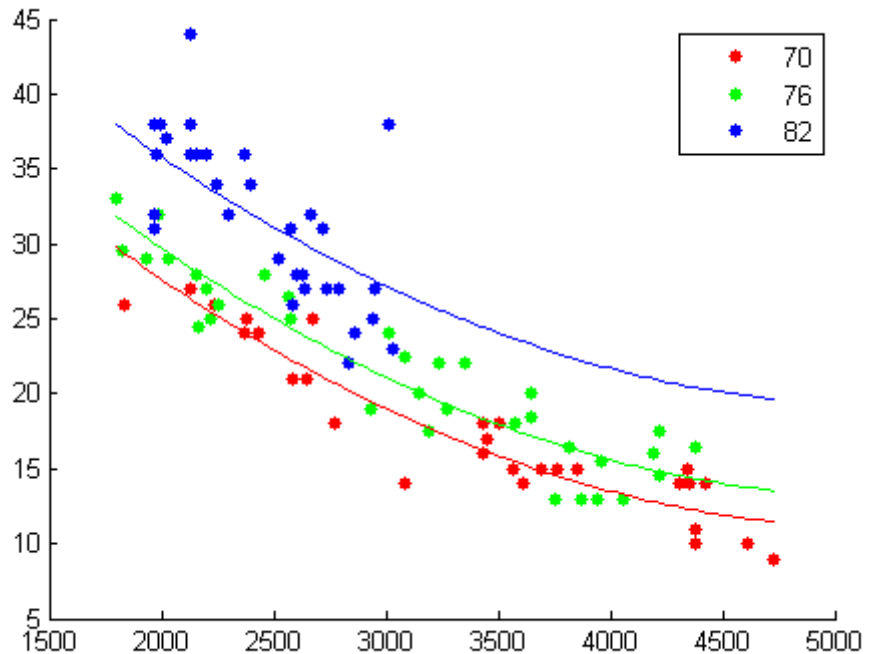
Create a scatter plot of the mileage versus weight.

```
gscatter(ds.Weight,ds.MPG,ds.Year);
```



Use `feval` to plot curves of the model predictions for the various years and weights.

```
w = linspace(min(ds.Weight),max(ds.Weight))';  
line(w,feval mdl,w,'70'),'Color','r')  
line(w,feval mdl,w,'76'),'Color','g')  
line(w,feval mdl,w,'82'),'Color','b')
```



Alternatives

`predict` gives the same predictions, but uses a single input array with one observation in each row, rather than one component in each input argument. `predict` also gives confidence intervals on its predictions.

`random` predicts with added noise.

See Also

`LinearModel` | `predict` | `random`

LinearModel.feval

Tutorials

- “feval” on page 9-37
- “Linear Regression Workflow” on page 9-40

How To

- “Linear Regression” on page 9-7

Purpose	Evaluate nonlinear regression model prediction
Syntax	<code>ypred = feval mdl, Xnew(1), Xnew(2), ..., Xnew(n)</code>
Description	<code>ypred = feval(mdl, Xnew(1), Xnew(2), ..., Xnew(n))</code> returns the predicted response of <code>mdl</code> to the input <code>[Xnew(1), Xnew(2), ..., Xnew(n)]</code> .
Input Arguments	<p>mdl</p> <p>Nonlinear regression model, constructed by <code>NonLinearModel.fit</code>.</p> <p>Xnew</p> <p>Predictor component. <code>Xnew(i)</code> can be one of:</p> <ul style="list-style-type: none">• Scalar• Vector• Array <p>Each nonscalar component must have the same size (number of elements in each dimension).</p> <p>If you pass just one <code>Xnew</code> array, <code>Xnew</code> can be a dataset array or an array of doubles, where each column of the array represents one predictor.</p>
Output Arguments	<p>ypred</p> <p>Predicted mean values at <code>Xnew</code>. <code>ypred</code> is the same size as each component of <code>Xnew</code>.</p>
Examples	<p>Predict a Nonlinear Model from a Dataset Array</p> <p>Create a nonlinear model for auto mileage based on the <code>carbig</code> data. Predict the mileage of an average automobile.</p> <p>Load the data and create a nonlinear model.</p>

NonLinearModel.feval

```
load carbig
ds = dataset(Horsepower,Weight,MPG);
modelfun = @(b,x)b(1) + b(2)*x(:,1).^b(3) + ...
    b(4)*x(:,2).^b(5);
beta0 = [-50 500 -1 500 -1];
mdl = NonLinearModel.fit(ds,modelfun,beta0);
```

Find the predicted mileage of an average auto. The data contain some observations with NaN, so compute the mean using `nanmean`.

```
Xnew = nanmean([Horsepower Weight]);
MPGnew = feval(mdl,Xnew)
```

```
MPGnew =  
  
    21.8073
```

Alternatives

`predict` gives the same predictions, but uses a single input array with one observation in each row, rather than one component in each input argument. `predict` also gives confidence intervals on its predictions.

`random` predicts with added noise.

See Also

[NonLinearModel](#) | [predict](#) | [random](#) |

Related Examples

- “[feval](#)” on page 9-209

Concepts

- “[Nonlinear Regression](#)” on page 9-196

Purpose Two-level full factorial design

Syntax `dFF2 = ff2n(n)`

Description `dFF2 = ff2n(n)` gives factor settings `dFF2` for a two-level full factorial design with `n` factors. `dFF2` is m -by- n , where m is the number of treatments in the full-factorial design. Each row of `dFF2` corresponds to a single treatment. Each column contains the settings for a single factor, with values of 0 and 1 for the two levels.

Examples `dFF2 = ff2n(3)`
`dFF2 =`

0	0	0
0	0	1
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1

See Also `fullfact`

TreeBagger.fillProximities

Purpose Proximity matrix for training data

Syntax `B = fillProximities(B)`
`B = fillProximities(B, 'param1', val1, 'param2', val2, ...)`

Description `B = fillProximities(B)` computes a proximity matrix for the training data and stores it in the Properties field of B.

`B = fillProximities(B, 'param1', val1, 'param2', val2, ...)` specifies optional parameter name/value pairs:

'trees' Either 'all' or a vector of indices of the trees in the ensemble to be used in computing the proximity matrix. Default is 'all'.

'nprint' Number of training cycles (grown trees) after which TreeBagger displays a diagnostic message showing training progress. Default is no diagnostic messages.

See Also `CompactTreeBagger.outlierMeasure` |
`CompactTreeBagger.proximity`

Purpose Find objects matching specified conditions

Syntax `hm = findobj(h, 'conditions')`

Description The `findobj` method of the `handle` class follows the same syntax as the MATLAB `findobj` command, except that the first argument must be an array of handles to objects.

`hm = findobj(h, 'conditions')` searches the handle object array `h` and returns an array of handle objects matching the specified conditions. Only the public members of the objects of `h` are considered when evaluating the conditions.

See Also `findobj` | `grandstream`

grandstream.findprop

Purpose Find property of MATLAB handle object

Syntax `p = findprop(h,'propname')`

Description `p = findprop(h,'propname')` finds and returns the `meta.property` object associated with property name `propname` of scalar handle object `h`. `propname` must be a string. It can be the name of a property defined by the class of `h` or a dynamic property added to scalar object `h`.

If no property named `propname` exists for object `h`, an empty `meta.property` array is returned.

See Also `dynamicprops` | `findobj` | `meta.property` | `grandstream`

Purpose F inverse cumulative distribution function

Syntax $X = \text{finv}(P, V1, V2)$

Description $X = \text{finv}(P, V1, V2)$ computes the inverse of the F cdf with numerator degrees of freedom $V1$ and denominator degrees of freedom $V2$ for the corresponding probabilities in P . P , $V1$, and $V2$ can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs.

$V1$ and $V2$ parameters must contain real positive values, and the values in P must lie on the interval $[0\ 1]$.

The F inverse function is defined in terms of the F cdf as

$$x = F^{-1}(p | v_1, v_2) = \{x : F(x | v_1, v_2) = p\}$$

where

$$p = F(x | v_1, v_2) = \int_0^x \frac{\Gamma\left[\frac{(v_1 + v_2)}{2}\right]}{\Gamma\left(\frac{v_1}{2}\right)\Gamma\left(\frac{v_2}{2}\right)} \left(\frac{v_1}{v_2}\right)^{\frac{v_1}{2}} \frac{t^{\frac{v_1-2}{2}}}{\left[1 + \left(\frac{v_1}{v_2}\right)t\right]^{\frac{v_1+v_2}{2}}} dt$$

Examples Find a value that should exceed 95% of the samples from an F distribution with 5 degrees of freedom in the numerator and 10 degrees of freedom in the denominator.

```
x = finv(0.95,5,10)
x =
    3.3258
```

You would observe values greater than 3.3258 only 5% of the time by chance.

See Also

[icdf](#) | [fcdf](#) | [fpdf](#) | [fstat](#) | [frnd](#)

How To

- “F Distribution” on page B-38

Purpose

Fit discriminant analysis classifier

Syntax

```
obj = ClassificationDiscriminant.fit(X,Y)
obj = ClassificationDiscriminant.fit(X,Y,Name,Value)
```

Description

`obj = ClassificationDiscriminant.fit(X,Y)` returns a discriminant analysis classifier based on the input variables (also known as predictors, features, or attributes) `X` and output (response) `Y`.

`obj = ClassificationDiscriminant.fit(X,Y,Name,Value)` fits a classifier with additional options specified by one or more `Name, Value` pair arguments. If you use one of the following five options, `obj` is of class `ClassificationPartitionedModel`: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Otherwise, `obj` is of class `ClassificationDiscriminant`.

Input Arguments

X

Matrix of numeric predictor values. Each column of `X` represents one variable, and each row represents one observation.

`ClassificationDiscriminant.fit` considers NaN values in `X` as missing values. `ClassificationDiscriminant.fit` does not use observations with missing values for `X` in the fit.

Y

Numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of `Y` represents the classification of the corresponding row of `X`.

`ClassificationDiscriminant.fit` considers NaN values in `Y` to be missing values. `ClassificationDiscriminant.fit` does not use observations with missing values for `Y` in the fit.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding

ClassificationDiscriminant.fit

value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1, Value1, ..., NameN, ValueN.

ClassNames

Array of class names. Use the data type that exists in Y.

Use ClassNames to order the classes or to select a subset of classes for training.

Default: Class names that exist in Y

Cost

Square matrix, where $Cost(i, j)$ is the cost of classifying a point into class j if its true class is i . Alternatively, Cost can be a structure S having two fields: S.ClassNames containing the group names as a variable of the same type as Y, and S.ClassificationCosts containing the cost matrix.

Default: $Cost(i, j) = 1$ if $i \neq j$, and $Cost(i, j) = 0$ if $i = j$

crossval

If 'on', creates a cross-validated classifier with 10 folds. You can use 'kfold', 'holdout', 'leaveout', or 'cvpartition' parameters to override this cross-validation setting. You can only use one of these options at a time for creating a cross-validated classifier: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

Alternatively, cross validate obj later using the crossval method.

Default: 'off'

cvpartition

Partition created with cvpartition to use in a cross-validated classifier. You can only use one of these options at a time for

creating a cross-validated classifier: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

delta

Threshold on linear coefficients, a nonnegative scalar. If a coefficient of `obj` has magnitude smaller than `delta`, `obj` sets this coefficient to 0, and so you can eliminate the corresponding predictor from the model. Set `delta` to a higher value to eliminate more predictors.

`delta` must be 0 for quadratic discriminant models.

Default: 0

discrimType

String specifying the discriminant type. Case-insensitive. One of:

- 'linear'
- 'quadratic'
- 'diagLinear'
- 'diagQuadratic'
- 'pseudoLinear'
- 'pseudoQuadratic'

Default: 'linear'

fillCoeffs

String, either 'on' or 'off', specifying whether to populate the `Coeffs` property in the classifier object. Setting to 'on' can be computationally intensive, especially when cross validating.

Default: 'on', except 'off' when cross validating

gamma

ClassificationDiscriminant.fit

Parameter for regularizing the correlation matrix of predictors.

- Linear discriminant — Scalar from 0 to 1.
 - If you pass a value strictly between 0 and 1, `ClassificationDiscriminant.fit` sets the discriminant type to 'Linear'.
 - If you pass 0 for gamma and 'Linear' for `DiscrimType`, and if the correlation matrix is singular, `ClassificationDiscriminant.fit` sets gamma to the minimal value required for inverting the covariance matrix.
 - If you set gamma to 1, `ClassificationDiscriminant.fit` sets the discriminant type to 'diagLinear'.
- Quadratic discriminant — Either 0 or 1.
 - If you pass 0 for gamma and 'Quadratic' for `DiscrimType`, and if one of the classes has a singular covariance matrix, `ClassificationDiscriminant.fit` errors.
 - If you set gamma to 1, `ClassificationDiscriminant.fit` sets the discriminant type to 'diagQuadratic'.

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. You can only use one of these options at a time for creating a cross-validated classifier: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

kfold

Number of folds to use in a cross-validated classifier, a positive integer. You can only use one of these options at a time for creating a cross-validated classifier: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

Default: 10

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these options at a time for creating a cross-validated classifier: 'cvpartition', 'holdout', 'kfold', or 'leaveout'.

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in X.

Default: {'x1', 'x2', ...}

prior

Prior probabilities for each class. Specify as one of:

- A string:
 - 'empirical' determines class probabilities from class frequencies in Y. If you pass observation weights, they are used to compute the class probabilities.
 - 'uniform' sets all class probabilities equal.
- A vector (one scalar value for each class)
- A structure S with two fields:
 - S.ClassNames containing the class names as a variable of the same type as Y
 - S.ClassProbs containing a vector of corresponding probabilities

Default: 'empirical'

ResponseName

Name of the response variable Y, a string.

ClassificationDiscriminant.fit

Default: 'Y'

SaveMemory

When 'on', `ClassificationDiscriminant.fit` does not store the full covariance matrix, but instead stores enough information to compute the matrix. The `predict` method computes the full covariance matrix for prediction, and does not store the matrix. When 'off', `ClassificationDiscriminant.fit` computes and stores the full covariance matrix in `obj`.

Set `SaveMemory` to 'on' when `X` has thousands of predictors.

Default: 'off'

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function.

String	Formula
'symmetric'	$2x - 1$
'invlogit'	$\log(x / (1-x))$
'ismax'	Set score for the class with the largest score to 1, and scores for all other classes to 0.
'symmetricismax'	Set score for the class with the largest score to 1, and scores for all other classes to -1.
'none'	x
'logit'	$1/(1 + e^{-x})$
'doublelogit'	$1/(1 + e^{-2x})$

String	Formula
'symmetriclogit'	$2/(1 + e^{-x}) - 1$
'sign'	-1 for $x < 0$ 0 for $x = 0$ 1 for $x > 0$

You can include your own function handle for transforming scores. Your function should accept a matrix (the original scores) and return a matrix of the same size (the transformed scores).

Default: 'none'

weights

Vector of observation weights. The length of `weights` is the number of rows in `X`. `ClassificationDiscriminant.fit` normalizes the weights to sum to 1.

Default: `ones(size(X,1),1)`

Output Arguments

obj

Discriminant analysis classifier. You can use `obj` to predict the response of new data using the `predict` method.

Definitions

Discriminant Classification

The model for discriminant analysis is:

- Each class (Y) generates data (X) using a multivariate normal distribution. That is, the model assumes X has a Gaussian mixture distribution (`gmdistribution`).
 - For linear discriminant analysis, the model has the same covariance matrix for each class, only the means vary.
 - For quadratic discriminant analysis, both means and covariances of each class vary.

ClassificationDiscriminant.fit

predict classifies so as to minimize the expected classification cost:

$$\hat{y} = \arg \min_{y=1, \dots, K} \sum_{k=1}^K \hat{P}(k | x) C(y | k),$$

where

- \hat{y} is the predicted classification.
- K is the number of classes.
- $\hat{P}(k | x)$ is the posterior probability of class k for observation x .
- $C(y | k)$ is the cost of classifying an observation as y when its true class is k .

For details, see “How the predict Method Classifies” on page 12-6.

Examples

Construct a discriminant analysis classifier for the Fisher iris data:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas, species)

obj =
ClassificationDiscriminant:
  PredictorNames: {'x1' 'x2' 'x3' 'x4'}
  ResponseName: 'Y'
  ClassNames: {'setosa' 'versicolor' 'virginica'}
  ScoreTransform: 'none'
  NObservations: 150
  DiscrimType: 'linear'
  Mu: [3x4 double]
  Coeffs: [3x3 struct]
```

Alternatives

The `classify` function also performs discriminant analysis. `classify` is usually more awkward to use:

- `classify` requires you to fit the classifier every time you make a new prediction.
- `classify` does not perform cross validation.
- `classify` requires you to fit the classifier when changing prior probabilities.

See Also

`ClassificationDiscriminant` | `ClassificationTree.fit`

How To

- “Discriminant Analysis” on page 12-3

ClassificationKNN.fit

Purpose Fit k -nearest neighbor classifier

Syntax
`mdl = ClassificationKNN.fit(X,Y)`
`mdl = ClassificationKNN.fit(X,Y,Name,Value)`

Description `mdl = ClassificationKNN.fit(X,Y)` returns a classification model based on the input variables (also known as predictors, features, or attributes) X and output (response) Y .

`mdl = ClassificationKNN.fit(X,Y,Name,Value)` fits a model with additional options specified by one or more `Name,Value` pair arguments.

If you use one of these options, `mdl` is of class `ClassificationPartitionedModel`: 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'. Otherwise, `mdl` is of class `ClassificationKNN`.

Input Arguments

X

Matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

Y

Grouping variables of response values with the same number of elements (rows) as X . Each entry in Y is the response to the data in the corresponding row of X .

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

BreakTies

String specifying the method `predict` uses to break ties if multiple classes have the same smallest cost. By default, ties occur when multiple classes have the same number of nearest points among the K nearest neighbors.

- 'nearest' — Use the class with the nearest neighbor among tied groups.
- 'random' — Use a random tiebreaker among tied groups.
- 'smallest' — Use the smallest index among tied groups.

Default: 'smallest'

BucketSize

Maximum number of data points in the leaf node of the kd -tree. This argument is meaningful only when `NSMethod` is 'kdtree'.

Default: 50

CategoricalPredictors

Specification of which predictors are categorical:

- 'all' — All predictors are categorical.
- [] — No predictors are categorical.

When you set `CategoricalPredictors` to 'all', the default `Distance` is 'hamming'.

Default: []

ClassNames

Array of class names. Use the data type that exists in Y .

Use `ClassNames` to order the classes or to select a subset of classes for training.

ClassificationKNN.fit

Default: Class names in Y

Cost

Square matrix, where $\text{Cost}(i, j)$ is the cost of classifying a point into class j if its true class is i . Alternatively, Cost can be a structure S having two fields: $S.\text{ClassNames}$ containing the group names as a variable of the same type as Y , and $S.\text{ClassificationCosts}$ containing the cost matrix.

Default: $\text{Cost}(i, j)=1$ if $i \neq j$, and $\text{Cost}(i, j)=0$ if $i=j$

Cov

Positive definite matrix, the covariance matrix when computing the Mahalanobis distance. This argument is only valid when 'Distance' is 'mahalanobis'.

Default: $\text{nancov}(X)$

crossval

If 'on', create a cross-validated model with 10 folds. Use the 'kfold', 'holdout', 'leaveout', or 'cvpartition' parameters to override this cross-validation setting. You can only use one parameter at a time to create a cross-validated model.

Alternatively, cross validate `model` later using the `crossval` method.

Default: 'off'

cvpartition

Partition created with `cvpartition` to use in a cross-validated model. You can only use one of these four options at a time for creating a cross-validated model: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Distance

String or function handle specifying the distance metric. The allowable strings depend on the `NSMethod` parameter, which you set in `ClassificationKNN.fit`, and which exists as a field in `ModelParams`.

NSMethod	Distance Metric Names
exhaustive	Any distance metric of <code>ExhaustiveSearcher</code>
kdtree	'cityblock', 'chebychev', 'euclidean', or 'minkowski'

For definitions, see “Distance Metrics” on page 13-9.

The distance metrics of `ExhaustiveSearcher`:

Value	Description
'cityblock'	City block distance.
'chebychev'	Chebychev distance (maximum coordinate difference).
'correlation'	One minus the sample linear correlation between observations (treated as sequences of values).
'cosine'	One minus the cosine of the included angle between observations (treated as vectors).
'euclidean'	Euclidean distance.
'hamming'	Hamming distance, percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, the percentage of nonzero coordinates that differ.

ClassificationKNN.fit

Value	Description
'mahalanobis'	Mahalanobis distance, computed using a positive definite covariance matrix C . The default value of C is the sample covariance matrix of X , as computed by <code>nancov(X)</code> . To specify a different value for C , use the 'Cov' name-value pair.
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use the 'P' name-value pair.
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between X and a query point is scaled, meaning divided by a scale value S . The default value of S is the standard deviation computed from X , <code>S = nanstd(X)</code> . To specify another value for S , use the <code>Scale</code> name-value pair.
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
@ <i>distfun</i>	Distance function handle. <i>distfun</i> has the form <pre>function D2 = DISTFUN(ZI,ZJ) % calculation of distance ...</pre> where <ul style="list-style-type: none">• ZI is a 1-by-N vector containing one row of X or Y.• ZJ is an M2-by-N matrix containing multiple rows of X or Y.

Value	Description
	<ul style="list-style-type: none"> D2 is an M2-by-1 vector of distances, and $D2(k)$ is the distance between observations ZI and ZJ (J, :).

Default: 'euclidean', except the default is 'hamming' when CategoricalPredictors is 'all'

DistanceWeight

String or function handle specifying the distance weighting function.

DistanceWeight	Meaning
'equal'	No weighting
'inverse'	Weight is 1/distance
'squaredinverse'	Weight is 1/distance ²
@fcn	<i>fcn</i> is a function that accepts a matrix of nonnegative distances, and returns a matrix the same size containing nonnegative distance weights. For example, 'squaredinverse' is equivalent to $@(d)d.^{-2}$.

Default: 'equal'

Exponent

Positive scalar specifying the exponent of Minkowski distance. This argument is only valid when 'Distance' is 'minkowski'.

Default: 2

holdout

ClassificationKNN.fit

Holdout validation tests the specified fraction of the data, and uses the remaining data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated model: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

IncludeTies

Logical value indicating whether `predict` includes all the neighbors whose distance values are equal to the *K*th smallest distance. If `IncludeTies` is `true`, `predict` includes all these neighbors. Otherwise, `predict` uses exactly *K* neighbors.

Default: `false`

kfold

Number of folds to use in a cross-validated model, a positive integer. You can only use one of these four options at a time for creating a cross-validated model: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these four options at a time for creating a cross-validated model: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

NSMethod

String specifying the nearest neighbor search method:

- 'kdtree' — Create and use a *kd*-tree to find nearest neighbors. 'kdtree' is valid when the distance metric is one of the following:
 - 'euclidean'

- 'cityblock'
- 'minkowski'
- 'chebyshev'
- 'exhaustive' — Use the exhaustive search algorithm. The distance values from all points in X to each point in Y are computed to find nearest neighbors.

Default: 'kdtree' when X has 10 or fewer columns, X is not sparse, and the distance metric is a 'kdtree' type; otherwise, 'exhaustive'

NumNeighbors

Positive integer specifying the number of nearest neighbors in X to find for classifying each point when predicting.

Default: 1

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in X.

Default: {'x1', 'x2', ...}

prior

Prior probabilities for each class. Specify as one of:

- A string:
 - 'empirical' determines class probabilities from class frequencies in Y. If you pass observation weights, they are used to compute the class probabilities.
 - 'uniform' sets all class probabilities equal.
- A vector (one scalar value for each class)

ClassificationKNN.fit

- A structure S with two fields:
 - S.ClassNames containing the class names as a variable of the same type as Y
 - S.ClassProbs containing a vector of corresponding probabilities

If you set values for both `weights` and `prior`, the weights are renormalized to add up to the value of the prior probability in the respective class.

Default: 'empirical'

ResponseName

Name of the response variable Y, a string.

Default: 'Response'

Scale

Vector containing nonnegative values, with length equal to the number of columns in X. Each coordinate difference between X and a query point is scaled by the corresponding element of Scale. This argument is only valid when 'Distance' is 'seuclidean'.

Default: `nanstd(X)`

weights

Vector of observation weights. The length of `weights` is the number of rows in X. `ClassificationKNN.fit` normalizes the weights in each class to add up to the value of the prior probability of the class.

Default: `ones(size(X,1),1)`

Output Arguments

mdl

k-nearest neighbor classifier model.

Definitions

Prediction

ClassificationKNN predicts the classification of a point X_{new} using a procedure equivalent to this:

- 1 Find the NumNeighbors points in the training set X that are nearest to X_{new} .
- 2 Find the NumNeighbors response values Y to those nearest points.
- 3 Assign the classification label Y_{new} that has largest posterior probability among the values in Y .

For details, see “Posterior Probability” on page 20-1830 in the predict documentation.

Examples

Construct a KNN Classifier

Construct a *k*-nearest neighbor classifier for the Fisher iris data, where $k = 5$.

Load the data.

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',5)
```

```
mdl =
```

```
ClassificationKNN:
  PredictorNames: {'x1' 'x2' 'x3' 'x4'}
```

ClassificationKNN.fit

```
ResponseName: 'Y'  
ClassNames: {'setosa' 'versicolor' 'virginica'}  
ScoreTransform: 'none'  
NObservations: 150  
Distance: 'euclidean'  
NumNeighbors: 5
```

Use a Different Metric

To use the Minkowski metric, you must use an exhaustive searcher.

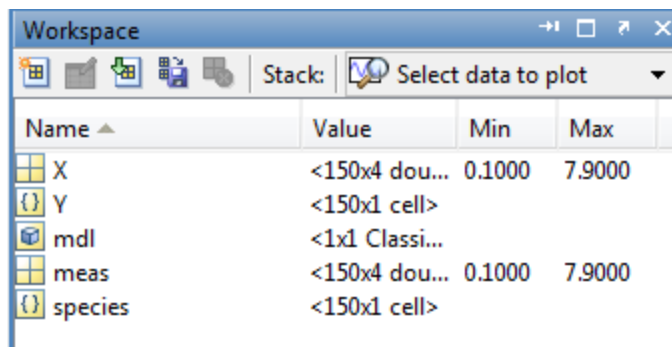
Load the data.

```
load fisheriris  
X = meas;  
Y = species;
```

Construct a classifier for 3-nearest neighbors with the Minkowski metric.

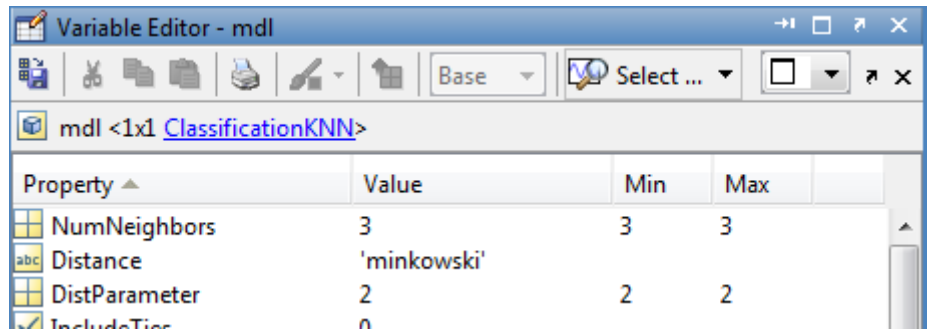
```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',3,...  
    'NSMethod','exhaustive','Distance','minkowski');
```

To examine mdl properties, double-click mdl in the Workspace window to open the Variable Editor.



The screenshot shows the MATLAB Workspace window with a toolbar and a table of variables. The toolbar includes icons for grid, home, save, copy, paste, and a dropdown menu labeled 'Stack: Select data to plot'. The table lists the following variables:

Name	Value	Min	Max
X	<150x4 dou...>	0.1000	7.9000
Y	<150x1 cell>		
mdl	<1x1 Classi...>		
meas	<150x4 dou...>	0.1000	7.9000
species	<150x1 cell>		



See Also

ClassificationKNN | predict |

Related Examples

- “Construct a KNN Classifier” on page 13-25
- “Modify a KNN Classifier” on page 13-27

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

ClassificationTree.fit

Purpose

Fit classification tree

Syntax

```
tree = ClassificationTree.fit(X,Y)
tree = ClassificationTree.fit(X,Y,Name,Value)
```

Description

`tree = ClassificationTree.fit(X,Y)` returns a classification tree based on the input variables (also known as predictors, features, or attributes) `X` and output (response) `Y`. `tree` is a binary tree, where each branching node is split based on the values of a column of `X`.

`tree = ClassificationTree.fit(X,Y,Name,Value)` fits a tree with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ,NameN,ValueN`. If you use one of the following five options, `tree` is of class `ClassificationPartitionedModel`: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Otherwise, `tree` is of class `ClassificationTree`.

Input Arguments

X

A matrix of numeric predictor values. Each column of `X` represents one variable, and each row represents one observation.

`ClassificationTree.fit` considers NaN values in `X` as missing values. `ClassificationTree.fit` does not use observations with all missing values for `X` in the fit. `ClassificationTree.fit` uses observations with some missing values for `X` to find splits on variables for which these observations have valid values.

Y

A numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings. Each row of `Y` represents the classification of the corresponding row of `X`. For numeric `Y`, consider using `RegressionTree.fit` instead of `ClassificationTree.fit`.

`ClassificationTree.fit` considers NaN values in `Y` to be missing values. `ClassificationTree.fit` does not use observations with missing values for `Y` in the fit.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

CategoricalPredictors

List of categorical predictors. Pass `CategoricalPredictors` as one of:

- A numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.
- A logical vector of length `p`, where a true entry means that the corresponding column of `X` is a categorical variable.
- 'all', meaning all predictors are categorical.
- A cell array of strings, where each element in the array is the name of a predictor variable. The names must match entries in `PredictorNames` values.
- A character matrix, where each row of the matrix is a name of a predictor variable. The names must match entries in `PredictorNames` values. Pad the names with extra blanks so each row of the character matrix has the same length.

Default: []

ClassNames

Array of class names. Use the data type that exists in `Y`.

ClassificationTree.fit

Use `ClassNames` to order the classes or to select a subset of classes for training.

Default: The class names that exist in `Y`

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class `j` if its true class is `i`. Alternatively, `Cost` can be a structure `S` having two fields: `S.ClassNames` containing the group names as a variable of the same type as `Y`, and `S.ClassificationCosts` containing the cost matrix.

Default: `Cost(i, j)=1` if `i≠j`, and `Cost(i, j)=0` if `i=j`

crossval

If `'on'`, grows a cross-validated decision tree with 10 folds. You can use `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'` parameters to override this cross-validation setting. You can only use one of these four parameters (`'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`) at a time when creating a cross-validated tree.

Alternatively, cross validate `tree` later using the `crossval` method.

Default: `'off'`

cvpartition

Partition created with `cvpartition` to use in a cross-validated tree. You can only use one of these four options at a time for creating a cross-validated tree: `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`.

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar

from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

MergeLeaves

When 'on', ClassificationTree.fit merges leaves that originate from the same parent node, and that give a sum of risk values greater or equal to the risk associated with the parent node. When 'off', ClassificationTree.fit does not merge leaves.

Default: 'on'

MinLeaf

Each leaf has at least MinLeaf observations per tree leaf. If you supply both MinParent and MinLeaf, ClassificationTree.fit uses the setting that gives larger leaves: $\text{MinParent} = \max(\text{MinParent}, 2 * \text{MinLeaf})$.

Default: 1

MinParent

ClassificationTree.fit

Each branch node in the tree has at least `MinParent` observations. If you supply both `MinParent` and `MinLeaf`, `ClassificationTree.fit` uses the setting that gives larger leaves: `MinParent=max(MinParent,2*MinLeaf)`.

Default: 10

NVarToSample

Number of predictors to select at random for each split. Can be a positive integer or 'all', which means use all available predictors.

Default: 'all'

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

Default: {'x1', 'x2', ...}

prior

Prior probabilities for each class. Specify as one of:

- A string:
 - 'empirical' determines class probabilities from class frequencies in `Y`. If you pass observation weights, they are used to compute the class probabilities.
 - 'uniform' sets all class probabilities equal.
- A vector (one scalar value for each class)
- A structure `S` with two fields:
 - `S.ClassNames` containing the class names as a variable of the same type as `Y`

- `S.ClassProbs` containing a vector of corresponding probabilities

If you set values for both `weights` and `prior`, the weights are renormalized to add up to the value of the prior probability in the respective class.

Default: 'empirical'

Prune

When 'on', `ClassificationTree.fit` grows the classification tree, and computes the optimal sequence of pruned subtrees. When 'off' `ClassificationTree.fit` grows the classification tree without pruning.

Default: 'on'

PruneCriterion

String with the pruning criterion, either 'error' or 'impurity'.

Default: 'error'

ResponseName

Name of the response variable Y , a string.

Default: 'Response'

ScoreTransform

Function handle for transforming scores, or string representing a built-in transformation function.

String	Formula
'symmetric'	$2x - 1$
'invlogit'	$\log(x / (1-x))$

ClassificationTree.fit

String	Formula
'ismax'	Set score for the class with the largest score to 1, and scores for all other classes to 0.
'symmetricismax'	Set score for the class with the largest score to 1, and scores for all other classes to -1.
'none'	x
'logit'	$1/(1 + e^{-x})$
'doublelogit'	$1/(1 + e^{-2x})$
'symmetriclogit'	$2/(1 + e^{-x}) - 1$
'sign'	-1 for $x < 0$ 0 for $x = 0$ 1 for $x > 0$

You can include your own function handle for transforming scores. Your function should accept a matrix (the original scores) and return a matrix of the same size (the transformed scores).

Default: 'none'

SplitCriterion

Criterion for choosing a split. One of 'gdi' (Gini's diversity index), 'twoing' for the twoing rule, or 'deviance' for maximum deviance reduction (also known as cross entropy).

Default: 'gdi'

Surrogate

When 'on', ClassificationTree.fit finds surrogate splits at each branch node. This setting improves the accuracy of predictions for data with missing values. The setting also enables

you to compute measures of predictive association between predictors. This setting can use much time and memory.

Default: 'off'

weights

Vector of observation weights. The length of `weights` is the number of rows in `X`. `ClassificationTree.fit` normalizes the weights in each class to add up to the value of the prior probability of the class.

Default: `ones(size(X,1),1)`

Output Arguments

tree

A classification tree object. You can use `tree` to predict the response of new data with the `predict` method.

Definitions

Impurity and Node Error

`ClassificationTree` splits nodes based on either *impurity* or *node error*. Impurity means one of several things, depending on your choice of the `SplitCriterion` name-value pair:

- Gini's Diversity Index (`gdi`) — The Gini index of a node is

$$1 - \sum_i p^2(i),$$

where the sum is over the classes i at the node, and $p(i)$ is the observed fraction of classes with class i that reach the node. A node with just one class (a *pure* node) has Gini index 0; otherwise the Gini index is positive. So the Gini index is a measure of node impurity.

- Deviance ('`deviance`') — With $p(i)$ defined as for the Gini index, the deviance of a node is

ClassificationTree.fit

$$-\sum_i p(i) \log p(i).$$

A pure node has deviance 0; otherwise, the deviance is positive.

- Twoing rule ('twoing') — Twoing is not a purity measure of a node, but is a different measure for deciding how to split a node. Let $L(i)$ denote the fraction of members of class i in the left child node after a split, and $R(i)$ denote the fraction of members of class i in the right child node after a split. Choose the split criterion to maximize

$$P(L)P(R) \left(\sum_i |L(i) - R(i)| \right)^2,$$

where $P(L)$ and $P(R)$ are the fractions of observations that split to the left and right respectively. If the expression is large, the split made each child node purer. Similarly, if the expression is small, the split made each child node similar to each other, and hence similar to the parent node, and so the split did not increase node purity.

- Node error — The node error is the fraction of misclassified classes at a node. If j is the class with largest number of training samples at a node, the node error is

$$1 - p(j).$$

Examples

Construct a classification tree for the data in `ionosphere.mat`:

```
load ionosphere
tc = ClassificationTree.fit(X,Y)

tc =
ClassificationTree:
    VarNames: {1x34 cell}
    CategoricalVars: []
    ClassNames: {'b' 'g'}
    Cost: [2x2 double]
    Prior: [0.3590 0.6410]
    TransformScore: 'none'
        X: [351x34 double]
        Y: {351x1 cell}
        W: [351x1 double]
    ModelParams: [1x1 classreg.learning.modelparams.TreeParams]
```

See Also `predict | ClassificationTree`

GeneralizedLinearModel.fit

Purpose Create generalized linear regression model

Syntax

```
mdl = GeneralizedLinearModel.fit(ds)
mdl = GeneralizedLinearModel.fit(X,y)
mdl = GeneralizedLinearModel.fit(...,modelspec)
mdl = GeneralizedLinearModel.fit(...,Name,Value)
mdl = GeneralizedLinearModel.fit(...,modelspec,Name,Value)
```

Description

`mdl = GeneralizedLinearModel.fit(ds)` creates a generalized linear model of a dataset array `ds`.

`mdl = GeneralizedLinearModel.fit(X,y)` creates a generalized linear model of the responses `y` to a data matrix `X`.

`mdl = GeneralizedLinearModel.fit(...,modelspec)` creates a generalized linear model as specified by `modelspec`.

`mdl = GeneralizedLinearModel.fit(...,Name,Value)` or `mdl = GeneralizedLinearModel.fit(...,modelspec,Name,Value)` creates a generalized linear model with additional options specified by one or more `Name,Value` pair arguments.

Tips

- The generalized linear model `mdl` is a standard linear model unless you specify otherwise with the `Distribution` name-value pair.
- For other methods such as `stepwise` or `devianceTest`, or properties of the `GeneralizedLinearModel` object, see `GeneralizedLinearModel`.

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors can be numeric, or can be any grouping variable type, such as logical or categorical (see “Grouping Variables” on page 2-72). The response must be numeric or logical.

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

x

Matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as X. Each entry in y is the response to the data in the corresponding row of X.

modelspec

Model specification. This is the starting model for the stepwise method. Possibilities:

- String specifying the type of model.

String	Model Type
'constant'	Model contains only a constant (intercept) term.
'linear'	Model contains an intercept and linear terms for each predictor.
'interactions'	Model contains an intercept, linear terms, and all products of pairs of distinct predictors (no squared terms).
'purequadratic'	Model contains an intercept, linear terms, and squared terms.

GeneralizedLinearModel.fit

String	Model Type
'quadratic'	Model contains an intercept, linear terms, interactions, and squared terms.
'polyijk'	Model is a polynomial with all terms up to degree <i>i</i> in the first predictor, degree <i>j</i> in the second predictor, etc. Use numerals 0 through 9. For example, 'poly2111' has a constant plus all linear and product terms, and also contains terms with predictor 1 squared.

- T-by-P+1 matrix, namely “Terms Matrix” on page 20-694, specifying terms to include in model, where T is the number of terms and P is the number of predictor variables, and plus one is for the response variable.
- String representing a “Formula” on page 20-697 in the form

`'Y ~ terms'`,

where the terms are in “Wilkinson Notation” on page 20-698.

Name-Value Pair Arguments

Specify optional comma-separated pairs of **Name**, **Value** arguments, where **Name** is the argument name and **Value** is the corresponding value. **Name** must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

BinomialSize

Vector or name of a variable of the same length as the response, specifying the size of the sample (number of trials) used in fitting the binomial distribution. This is the *n* parameter for the fitted binomial distribution. **BinomialSize** applies only when the **Distribution** parameter is 'binomial'.

`BinomialSize` can be a scalar, meaning all observations have the same number of trials.

As an alternative to `BinomialSize`, you can specify the response as a two-column vector with counts in column 1 and `BinomialSize` in column 2.

Default: 1

CategoricalVars

Identify the categorical variables. Choices:

- Cell array of strings of the variable names in the `ds` dataset array.
- Logical or numerical index vector indicating which data columns are categorical. For example, if predictors 2 and 3 out of 6 are categorical, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: For data matrix `X`, default is `[]` (none). For dataset array `ds`, default is to treat `ds` variables as categorical if they are categorical, logical, character arrays, or cell arrays of strings.

DispersionFlag

Logical value that applies only to 'binomial' and 'poisson' distributions. `true` causes the fitting function to estimate a dispersion parameter when computing standard errors. `false` causes the fitting function to use the theoretical value. The fitting function always estimates the dispersion for other distributions.

Default: `false` for 'binomial' and 'poisson' distributions

GeneralizedLinearModel.fit

Distribution

Name of the distribution of the response, one of:

'normal'	Normal distribution
'binomial'	Binomial distribution
'poisson'	Poisson distribution
'gamma'	Gamma distribution
'inverse gaussian'	Inverse Gaussian distribution

Default: 'normal'

Exclude

Logical or numerical index vector indicating which observations to exclude from the fit. For example, to exclude observations 2 and 3 out of 6, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: []

Intercept

Logical value indicating whether to include a constant term (intercept) in the model. Use `Intercept` only when you specify the model by a string, not a formula or matrix.

Default: true

Link

The link function to use in place of the canonical link. The link function defines the relationship $f(\mu) = X^*b$ between the mean response μ and the linear combination of predictors X^*b . Specify the link as follows.

Link Function Name	Link Function	Mean (Inverse) Function
'identity'	$f(\mu) = \mu$	$\mu = Xb$
'log'	$f(\mu) = \log(\mu)$	$\mu = \exp(Xb)$
'logit'	$f(\mu) = \log(\mu/(1-\mu))$	$\mu = \exp(Xb) / (1 + \exp(Xb))$
'probit'	$f(\mu) = \Phi^{-1}(\mu)$	$\mu = \Phi(Xb)$
'comploglog'	$f(\mu) = \log(-\log(1 - \mu))$	$\mu = 1 - \exp(-\exp(Xb))$
'reciprocal'	$f(\mu) = \log(-\log(\mu))$	$\mu = \exp(-\exp(Xb))$
p (a number)	$f(\mu) = \mu^p$	$\mu = Xb^{1/p}$
S (a structure) S has three fields, each a function handle that accepts a vector of inputs and returns a vector the same size: <ul style="list-style-type: none"> • S.Link — The link function • S.Inverse — The inverse link function • S.Derivative — The derivative of the link function 	$f(\mu) = S.Link(\mu)$	$\mu = S.Inverse(Xb)$

Default: The canonical link function (see “Definitions” on page 20-694)

Offset

GeneralizedLinearModel.fit

Vector or name of a variable with the same length as the response. `GeneralizedLinearModel.fit` and `GeneralizedLinearModel.stepwise` use `Offset` as an additional predictor, with a coefficient value fixed at 1.0. In other words, the formula for fitting is

$$\mu \sim \text{Offset} + (\text{terms involving real predictors})$$

with the `Offset` predictor having coefficient 1.

For example, consider a Poisson regression model. Suppose the number of counts is known for theoretical reasons to be proportional to a predictor `A`. By using the log link function and by specifying `log(A)` as an offset, you can force the model to satisfy this theoretical constraint.

Default: []

PredictorVars

Identify the predictors to use for fitting. Choices:

- Cell array of strings of the variable names. The strings should be names in the `ds` dataset array, or the `VarNames` name-value pair.
- Logical or numerical index vector indicating which predictors to use. For example, to use predictors 2 and 3 out of 6, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: All variables in `X`, or all variables in `ds` except for `ResponseVar`

ResponseVar

Variable that the fitting function uses for response data. Give either the variable name or its column number. Typically, you use `ResponseVar` when fitting a dataset array `ds`. Choices are:

- String of the variable name.
- Logical or numerical index vector indicating which predictors to use. For example, to use the fourth variable as the response out of six variables, pass either

```
'ResponseVar', [4]
```

or

```
'ResponseVar', logical([0 0 0 1 0 0])
```

Default: Last column of `ds`

VarNames

Cell array of strings, first naming the columns of X , and with the response variable y last. Not applicable to variables in a dataset array, because those variables already have names.

Default: `{ 'x1', 'x2', ..., 'xn', 'y' }`, where n is the number of columns of X

Weights

Vector of nonnegative observation weights.

Default: `ones(size(y))`

Output Arguments

mdl

Generalized linear model representing a least-squares fit of the link of the response to the data.

GeneralizedLinearModel.fit

Definitions

Terms Matrix

A terms matrix is a T -by- $P+1$ matrix specifying terms in a model, where T is the number of terms, P is the number of predictor variables, and plus one is for the response variable. The value of $T(i, j)$ is the exponent of variable j in term i . For example, if there are three predictor variables A , B , and C :

```
[0 0 0 0] % constant term or intercept
[0 1 0 0] % B; equivalently, A^0 * B^1 * C^0
[1 0 1 0] % A*C
[2 0 0 0] % A^2
[0 1 2 0] % B*(C^2)
```

The 0 at the end of each term represents the response variable. In general,

- If you have the variables in a dataset array, then a 0 must represent the response variable depending on the position of the response variable in the dataset array. For example:

Load sample data and define the dataset array.

```
load hospital
ds = dataset(hospital.Sex,hospital.BloodPressure(:,1),hospital.Age,...
hospital.Smoker,'VarNames',{'Sex','BloodPressure','Age','Smoker'});
```

Represent the linear model 'BloodPressure ~ 1 + Sex + Age + Smoker' in a terms matrix. The response variable is in the second column of the data set array, so there must be a column of zeros for the response variable in the second column of the term matrix.

```
T = [0 0 0 0;1 0 0 0;0 0 1 0;0 0 0 1]
```

T =

```
0    0    0    0
1    0    0    0
0    0    1    0
```



```
0 0 0 1
```

Redefine the dataset array.

```
ds = dataset(hospital.BloodPressure(:,1),hospital.Sex,hospital.Age,  
hospital.Smoker,'VarNames',{'BloodPressure','Sex','Age','Smoker'});
```

Now, the response variable is the first term in the data set array. Specify the same linear model, 'BloodPressure ~ 1 + Sex + Age + Smoker', using a term matrix.

```
T = [0 0 0 0;0 1 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```
0 0 0 0  
0 1 0 0  
0 0 1 0  
0 0 0 1
```

- If you have the predictor and response variables in a matrix and column vector, then you must include a 0 for the response variable at the end of each term. For example:

Load sample data and define the matrix of predictors.

```
load carsmall  
X = [Acceleration,Weight];
```

Specify the model 'MPG ~ Acceleration + Weight + Acceleration:Weight + Weight^2' using a term matrix and fit the model to data. This model includes the main effect and two way interaction terms for the variables, Acceleration and Weight, and a second order term for the variable, Weight.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0;0 2 0]
```

```
T =
```

GeneralizedLinearModel.fit

```
0 0 0
1 0 0
0 1 0
1 1 0
0 2 0
```

Fit a linear model.

```
mdl = LinearModel.fit(X,MPG,T)
```

```
mdl =
```

Linear regression model:

```
y ~ 1 + x1*x2 + x2^2
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	48.906	12.589	3.8847	0.00019665
x1	0.54418	0.57125	0.95261	0.34337
x2	-0.012781	0.0060312	-2.1192	0.036857
x1:x2	-0.00010892	0.00017925	-0.6076	0.545
x2^2	9.7518e-07	7.5389e-07	1.2935	0.19917

Number of observations: 94, Error degrees of freedom: 89

Root Mean Squared Error: 4.1

R-squared: 0.751, Adjusted R-Squared 0.739

F-statistic vs. constant model: 67, p-value = 4.99e-26

Only the intercept and x2 term, which corresponds to the Weight variable, are significant at the 5% significance level.

Now, perform a stepwise regression with a constant model as the starting model and a linear model with interactions as the upper model.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0];
mdl = LinearModel.stepwise(X,MPG,[0 0 0], 'upper', T)
```

1. Adding x2, FStat = 259.3087, pValue = 1.643351e-28

mdl =

Linear regression model:

$$y \sim 1 + x2$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	49.238	1.6411	30.002	2.7015e-49
x2	-0.0086119	0.0005348	-16.103	1.6434e-28

Number of observations: 94, Error degrees of freedom: 92

Root Mean Squared Error: 4.13

R-squared: 0.738, Adjusted R-Squared 0.735

F-statistic vs. constant model: 259, p-value = 1.64e-28

The results of the stepwise regression are consistent with the results of `LinearModel.fit` in the previous step.

Formula

A formula for model specification is a string of the form

`'Y ~ terms'`,

where

- *Y* is the response name.
- *terms* contains
 - Variable names
 - + means include the next variable
 - - means do not include the next variable
 - : defines an interaction, a product of terms
 - * defines an interaction **and all lower-order terms**

GeneralizedLinearModel.fit

- \wedge raises the predictor to a power, exactly as in * repeated, so \wedge includes lower order terms as well
- () groups terms

Note Formulas include a constant (intercept) term by default. To exclude a constant term from the model, include - 1 in the formula.

For example,

'Y ~ A + B + C' means a three-variable linear model with intercept.

'Y ~ A + B + C - 1' is a three-variable linear model without intercept.

'Y ~ A + B + C + B^2' is a three-variable model with intercept and a B^2 term.

'Y ~ A + B^2 + C' is the same as the previous example because B^2 includes a B term.

'Y ~ A + B + C + A:B' includes an A*B term.

'Y ~ A*B + C' is the same as the previous example because $A*B = A + B + A:B$.

'Y ~ A*B*C - A:B:C' has all interactions among A, B, and C, except the three-way interaction.

'Y ~ A*(B + C + D)' has all linear terms, plus products of A with each of the other variables.

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k, where k is a positive integer	A, A ² , ..., A ^k

Wilkinson Notation	Factors in Standard Notation
A+B	A, B
A*B	A, B, A*B
A:B	A*B only
-B	Do not include B
A*B+C	A, B, C, A*B
A+B+C+A:B	A, B, C, A*B
A*B*C - A:B:C	A, B, C, A*B, A*C, B*C
A*(B + C)	A, B, C, A*B, A*C

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using -1.

Canonical Link Function

The default link function for a generalized linear model is the *canonical link function*.

Canonical Link Functions for Generalized Linear Models

Distribution	Link Function Name	Link Function	Mean (Inverse) Function
'normal'	'identity'	$f(\mu) = \mu$	$\mu = Xb$
'binomial'	'logit'	$f(\mu) = \log(\mu/(1-\mu))$	$\mu = \exp(Xb) / (1 + \exp(Xb))$
'poisson'	'log'	$f(\mu) = \log(\mu)$	$\mu = \exp(Xb)$
'gamma'	-1	$f(\mu) = 1/\mu$	$\mu = 1/(Xb)$
'inverse gaussian'	-2	$f(\mu) = 1/\mu^2$	$\mu = (Xb)^{-1/2}$

GeneralizedLinearModel.fit

Examples

Fit a Generalized Linear Model

Make a logistic binomial model of the probability of smoking as a function of age, weight, and sex, using a two-way interactions model.

Load the hospital dataset array.

```
load hospital
ds = hospital; % just to use the ds name
```

Specify the model using a formula that allows up to two-way interactions.

```
modelspec = 'Smoker ~ Age*Weight*Sex - Age:Weight:Sex';
```

Create the generalized linear model.

```
mdl = GeneralizedLinearModel.fit(ds,...
    modelspec,'Distribution','binomial')
```

```
mdl =
```

Generalized Linear regression model:

```
logit(Smoker) ~ 1 + Sex*Age + Sex*Weight + Age*Weight
Distribution = Binomial
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	-6.0492	19.749	-0.3063	0.75938
Sex_Male	-2.2859	12.424	-0.18399	0.85402
Age	0.11691	0.50977	0.22934	0.81861
Weight	0.031109	0.15208	0.20455	0.83792
Sex_Male:Age	0.020734	0.20681	0.10025	0.92014
Sex_Male:Weight	0.01216	0.053168	0.22871	0.8191
Age:Weight	-0.00071959	0.0038964	-0.18468	0.85348

100 observations, 93 error degrees of freedom

Dispersion: 1

Chi^2-statistic vs. constant model: 5.07, p-value = 0.535

The large p -value indicates the model might not differ statistically from a constant.

Alternatives

Use `GeneralizedLinearModel.stepwise` to select a model specification automatically. Use `step`, `addTerms`, or `removeTerms` to adjust a fitted model.

References

[1] Collett, D. *Modeling Binary Data*. New York: Chapman & Hall, 2002.

[2] Dobson, A. J. *An Introduction to Generalized Linear Models*. New York: Chapman & Hall, 1990.

[3] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*. New York: Chapman & Hall, 1990.

See Also

`GeneralizedLinearModel` | `GeneralizedLinearModel.stepwise` |

Related Examples

- “Generalized Linear Model Workflow” on page 9-171

Concepts

- “Generalized Linear Models” on page 9-141

gmdistribution.fit

Purpose Gaussian mixture parameter estimates

Syntax
`obj = gmdistribution.fit(X,k)`
`obj = gmdistribution.fit(...,param1,val1,param2,val2,...)`

Description `obj = gmdistribution.fit(X,k)` uses an Expectation Maximization (EM) algorithm to construct an object `obj` of the `gmdistribution` class containing maximum likelihood estimates of the parameters in a Gaussian mixture model with `k` components for data in the n -by- d matrix `X`, where n is the number of observations and d is the dimension of the data.

`gmdistribution` treats NaN values as missing data. Rows of `X` with NaN values are excluded from the fit.

`obj = gmdistribution.fit(...,param1,val1,param2,val2,...)` provides control over the iterative EM algorithm. Parameters and values are listed below.

Parameter	Value
'Start'	Method used to choose initial component parameters. One of the following: <ul style="list-style-type: none">• 'randSample' — To select <code>k</code> observations from <code>X</code> at random as initial component means. The mixing proportions are uniform. The initial covariance matrices for all components are diagonal, where the element <code>j</code> on the diagonal is the variance of <code>X(:,j)</code>. This is the default.• <code>S</code> — A structure array with fields <code>mu</code>, <code>Sigma</code>, and <code>PComponents</code>. See <code>gmdistribution</code> for descriptions of values.• <code>s</code> — A vector of length n containing an initial guess of the component index for each point.
'Replicates'	A positive integer giving the number of times to repeat the EM algorithm, each time with a new set of

Parameter	Value
	parameters. The solution with the largest likelihood is returned. A value larger than 1 requires the 'randSample' start method. The default is 1.
'CovType'	'diagonal' if the covariance matrices are restricted to be diagonal; 'full' otherwise. The default is 'full'.
'SharedCov'	Logical true if all the covariance matrices are restricted to be the same (pooled estimate); logical false otherwise.
'Regularize'	A nonnegative regularization number added to the diagonal of covariance matrices to make them positive-definite. The default is 0.
'Options'	Options structure for the iterative EM algorithm, as created by <code>statset</code> . <code>gmdistribution.fit</code> uses the parameters 'Display' with a default value of 'off', 'MaxIter' with a default value of 100, and 'TolFun' with a default value of $1e-6$.

In some cases, `gmdistribution` may converge to a solution where one or more of the components has an ill-conditioned or singular covariance matrix.

The following issues may result in an ill-conditioned covariance matrix:

- The number of dimension of your data is relatively high and there are not enough observations.
- Some of the features (variables) of your data are highly correlated.
- Some or all the features are discrete.
- You tried to fit the data to too many components.

In general, you can avoid getting ill-conditioned covariance matrices by using one of the following precautions:

- Pre-process your data to remove correlated features.
- Set 'SharedCov' to true to use an equal covariance matrix for every component.
- Set 'CovType' to 'diagonal'.
- Use 'Regularize' to add a very small positive number to the diagonal of every covariance matrix.
- Try another set of initial values.

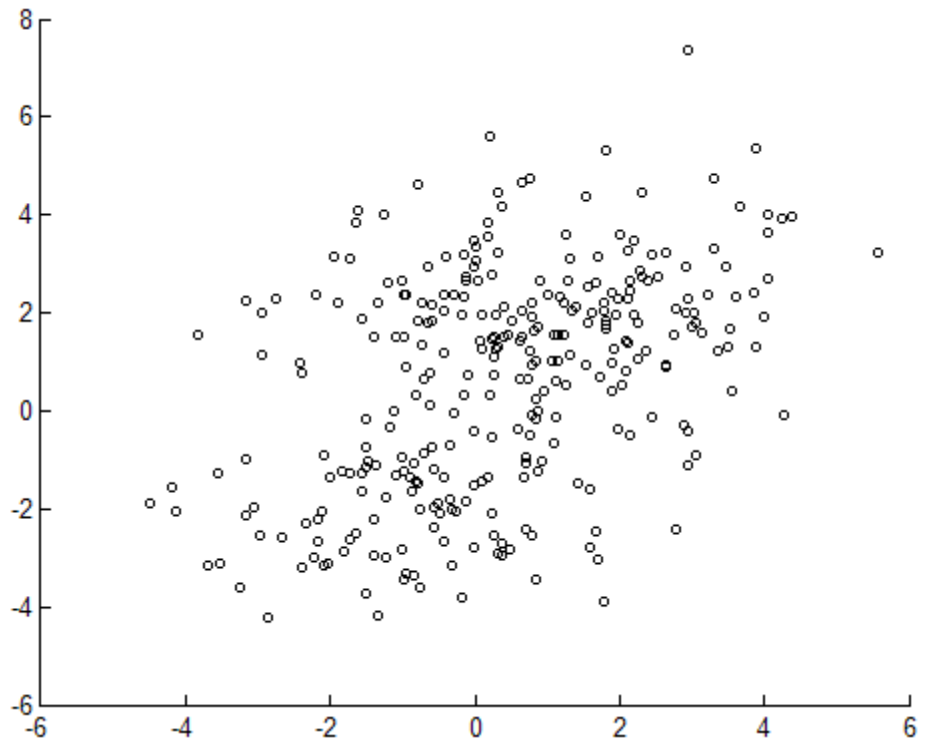
In other cases `gmdistribution` may pass through an intermediate step where one or more of the components has an ill-conditioned covariance matrix. Trying another set of initial values may avoid this issue without altering your data or model.

Examples

Generate data from a mixture of two bivariate Gaussian distributions using the `mvnrnd` function:

```
MU1 = [1 2];
SIGMA1 = [2 0; 0 .5];
MU2 = [-3 -5];
SIGMA2 = [1 0; 0 1];
X = [mvnrnd(MU1,SIGMA1,1000);mvnrnd(MU2,SIGMA2,1000)];

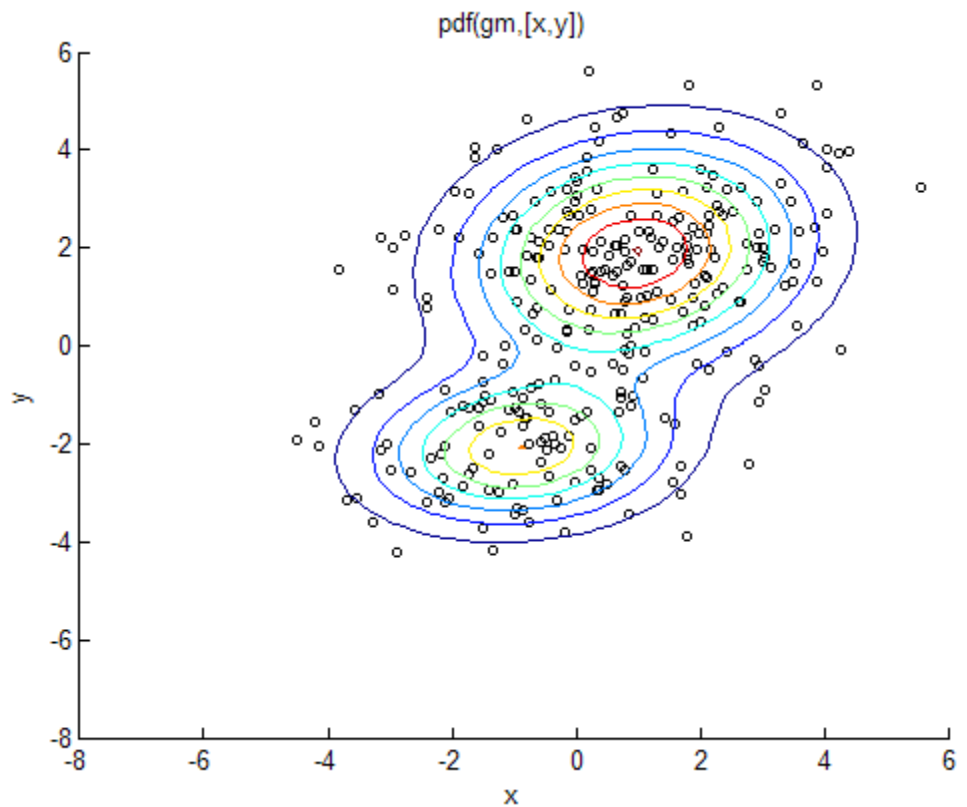
scatter(X(:,1),X(:,2),10, '.')
hold on
```



Next, fit a two-component Gaussian mixture model:

```
options = statset('Display','final');  
obj = gmdistribution.fit(X,2,'Options',options);  
10 iterations, log-likelihood = -7046.78  
  
h = ezcontour(@(x,y)pdf(obj,[x y]),[-8 6],[-8 6]);
```

gmdistribution.fit



Among the properties of the fit are the parameter estimates:

```
ComponentMeans = obj.mu
```

```
ComponentMeans =
```

```
    0.9391    2.0322
```

```
   -2.9823   -4.9737
```

```
ComponentCovariances = obj.Sigma
```

```
ComponentCovariances(:,:,1) =
```

```
    1.7786   -0.0528
```

```
   -0.0528    0.5312
```

```
ComponentCovariances(:,:,2) =  
    1.0491   -0.0150  
   -0.0150    0.9816  
  
MixtureProportions = obj.PComponents  
MixtureProportions =  
    0.5000    0.5000
```

The Akaike information is minimized by the two-component model:

```
AIC = zeros(1,4);  
obj = cell(1,4);  
for k = 1:4  
    obj{k} = gmdistribution.fit(X,k);  
    AIC(k) = obj{k}.AIC;  
end  
  
[minAIC,numComponents] = min(AIC);  
numComponents  
numComponents =  
    2  
  
model = obj{2}  
model =  
Gaussian mixture distribution  
with 2 components in 2 dimensions  
Component 1:  
Mixing proportion: 0.500000  
Mean:    0.9391    2.0322  
Component 2:  
Mixing proportion: 0.500000  
Mean:   -2.9823   -4.9737
```

Both the Akaike and Bayes information are negative log-likelihoods for the data with penalty terms for the number of estimated parameters. They are often used to determine an appropriate number of components for a model when the number of components is unspecified.

gmdistribution.fit

References

[1] McLachlan, G., and D. Peel. *Finite Mixture Models*. Hoboken, NJ: John Wiley & Sons, Inc., 2000.

See Also

gmdistribution | cluster

Purpose

Create linear regression model

Syntax

```
mdl = LinearModel.fit(ds)
mdl = LinearModel.fit(X,y)
mdl = LinearModel.fit(...,modelspec)
mdl = LinearModel.fit(...,Name,Value)
mdl = LinearModel.fit(...,modelspec,Name,Value)
```

Description

`mdl = LinearModel.fit(ds)` creates a linear model of a dataset array `ds`.

`mdl = LinearModel.fit(X,y)` creates a linear model of the responses `y` to a data matrix `X`.

`mdl = LinearModel.fit(...,modelspec)` creates a linear model of the specified type.

`mdl = LinearModel.fit(...,Name,Value)` or `mdl = LinearModel.fit(...,modelspec,Name,Value)` creates a linear model with additional options specified by one or more `Name,Value` pair arguments.

Tips

- Use robust fitting (`RobustOpts` name-value pair) to reduce the effect of outliers automatically.
- Do not use robust fitting when you want to subsequently adjust a model using `step`.
- For other methods such as `stepwise` or `anova`, or properties of the `LinearModel` object, see `LinearModel`.

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors can be numeric, or can be any grouping variable type, such as logical or categorical (see “Grouping Variables” on page 2-72). The response must be numeric or logical.

LinearModel.fit

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

x

Matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as `X`. Each entry in `y` is the response to the data in the corresponding row of `X`.

modelspec

Model specification. This is the starting model for the stepwise method. Possibilities:

String	Model Type
'constant'	Model contains only a constant (intercept) term.
'linear'	Model contains an intercept and linear terms for each predictor.
'interactions'	Model contains an intercept, linear terms, and all products of pairs of distinct predictors (no squared terms).
'purequadratic'	Model contains an intercept, linear terms, and squared terms.

String	Model Type
'quadratic'	Model contains an intercept, linear terms, interactions, and squared terms.
'polyijk'	Model is a polynomial with all terms up to degree i in the first predictor, degree j in the second predictor, etc. Use numerals 0 through 9. For example, 'poly2111' has a constant plus all linear and product terms, and also contains terms with predictor 1 squared.

- T-by-P+1 matrix, namely “Terms Matrix” on page 20-715, specifying terms to include in model, where T is the number of terms and P is the number of predictor variables, and plus one is for the response variable.
- String representing a “Formula” on page 20-719 in the form

`'Y ~ terms'`,

where the terms are in “Wilkinson Notation” on page 20-720.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

CategoricalVars

Identify the categorical variables. Choices:

- Cell array of strings of the variable names in the `ds` dataset array.

LinearModel.fit

- Logical or numerical index vector indicating which data columns are categorical. For example, if predictors 2 and 3 out of 6 are categorical, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: For data matrix X , default is [] (none). For dataset array ds , default is to treat ds variables as categorical if they are categorical, logical, character arrays, or cell arrays of strings.

Exclude

Logical or numerical index vector indicating which observations to exclude from the fit. For example, to exclude observations 2 and 3 out of 6, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: []

Intercept

Logical value indicating whether to include a constant term (intercept) in the model. Use `Intercept` only when you specify the model by a string, not a formula or matrix.

Default: true

PredictorVars

Identify the predictors to use for fitting. Choices:

- Cell array of strings of the variable names. The strings should be names in the `ds` dataset array, or the `VarNames` name-value pair.
- Logical or numerical index vector indicating which predictors to use. For example, to use predictors 2 and 3 out of 6, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: All variables in `X`, or all variables in `ds` except for `ResponseVar`

ResponseVar

Variable that the fitting function uses for response data. Give either the variable name or its column number. Typically, you use `ResponseVar` when fitting a dataset array `ds`. Choices are:

- String of the variable name.
- Logical or numerical index vector indicating which predictors to use. For example, to use the fourth variable as the response out of six variables, pass either

```
'ResponseVar', [4]
```

or

```
'ResponseVar', logical([0 0 0 1 0 0])
```

Default: Last column of `ds`

RobustOpts

Indicator of which type of robust fitting to use:

LinearModel.fit

- 'off' — No robust fitting, `LinearModel.fit` uses ordinary least squares.
- 'on' — Robust fitting using the 'bisquare' weight function.
- String — Name of the robust fitting weight function from the following table. `LinearModel.fit` uses the listed default tuning constant.
- Structure with the string `RobustWgtFun` and optional scalar `Tune` fields — `LinearModel.fit` uses the `RobustWgtFun` weight function and `Tune` tuning constant from the structure. If you do not supply a `Tune` field, the fitting function uses the default tuning constant.

Weight Function	Equation	Default Tuning Constant
'andrews'	$w = (\text{abs}(r) < \pi) \cdot \sin(r) \cdot / r$	1.339
'bisquare' (default)	$w = (\text{abs}(r) < 1) \cdot (1 - r.^2).^2$	4.685
'cauchy'	$w = 1 \cdot / (1 + r.^2)$	2.385
'fair'	$w = 1 \cdot / (1 + \text{abs}(r))$	1.400
'huber'	$w = 1 \cdot / \max(1, \text{abs}(r))$	1.345
'logistic'	$w = \tanh(r) \cdot / r$	1.205
'ols'	Ordinary least squares (no weighting function)	None
'talwar'	$w = 1 \cdot * (\text{abs}(r) < 1)$	2.795
'welsch'	$w = \exp(-(r.^2))$	2.985

- Structure with the function handle `RobustWgtFun` and optional scalar `Tune` fields — `LinearModel.fit` uses the `RobustWgtFun` weight function and `Tune` tuning constant from the structure. Specify `RobustWgtFun` as a function handle that accepts a

vector of residuals, and returns a vector of weights the same size. The fitting function scales the residuals, dividing by the tuning constant (default 1) and by an estimate of the error standard deviation before it calls the weight function.

Default: 'off'

VarNames

Cell array of strings, first naming the columns of X, and with the response variable y last. Not applicable to variables in a dataset array, because those variables already have names.

Default: { 'x1', 'x2', ..., 'xn', 'y' }, where n is the number of columns of X

Weights

Vector of nonnegative observation weights.

Default: ones(size(y))

Output Arguments

mdl

Linear model representing a least-squares fit of the response to the data. If the `Robust` name-value pair was not `[]` or `'ols'`, the model is not a least-squares fit, but uses the robust fitting function.

Definitions

Terms Matrix

A terms matrix is a T-by-P+1 matrix specifying terms in a model, where T is the number of terms, P is the number of predictor variables, and plus one is for the response variable. The value of $T(i, j)$ is the exponent of variable j in term i. For example, if there are three predictor variables A, B, and C:

```
[0 0 0 0] % constant term or intercept  
[0 1 0 0] % B; equivalently, A^0 * B^1 * C^0
```

LinearModel.fit

```
[1 0 1 0] % A*C
[2 0 0 0] % A^2
[0 1 2 0] % B*(C^2)
```

The 0 at the end of each term represents the response variable. In general,

- If you have the variables in a dataset array, then a 0 must represent the response variable depending on the position of the response variable in the dataset array. For example:

Load sample data and define the dataset array.

```
load hospital
ds = dataset(hospital.Sex,hospital.BloodPressure(:,1),hospital.Age,...
hospital.Smoker,'VarNames',{'Sex','BloodPressure','Age','Smoker'});
```

Represent the linear model 'BloodPressure ~ 1 + Sex + Age + Smoker' in a terms matrix. The response variable is in the second column of the data set array, so there must be a column of zeros for the response variable in the second column of the term matrix.

```
T = [0 0 0 0;1 0 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```
    0    0    0    0
    1    0    0    0
    0    0    1    0
    0    0    0    1
```

Redefine the dataset array.

```
ds = dataset(hospital.BloodPressure(:,1),hospital.Sex,hospital.Age,...
hospital.Smoker,'VarNames',{'BloodPressure','Sex','Age','Smoker'});
```

Now, the response variable is the first term in the data set array. Specify the same linear model, 'BloodPressure ~ 1 + Sex + Age + Smoker', using a term matrix.

```
T = [0 0 0 0;0 1 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```
    0    0    0    0
    0    1    0    0
    0    0    1    0
    0    0    0    1
```

- If you have the predictor and response variables in a matrix and column vector, then you must include a 0 for the response variable at the end of each term. For example:

Load sample data and define the matrix of predictors.

```
load carsmall
X = [Acceleration,Weight];
```

Specify the model 'MPG ~ Acceleration + Weight + Acceleration:Weight + Weight^2' using a term matrix and fit the model to data. This model includes the main effect and two way interaction terms for the variables, Acceleration and Weight, and a second order term for the variable, Weight.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0;0 2 0]
```

```
T =
```

```
    0    0    0
    1    0    0
    0    1    0
    1    1    0
    0    2    0
```

Fit a linear model.

```
mdl = LinearModel.fit(X,MPG,T)
```

LinearModel.fit

```
mdl =
```

```
Linear regression model:
```

$$y \sim 1 + x1*x2 + x2^2$$

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	48.906	12.589	3.8847	0.00019665
x1	0.54418	0.57125	0.95261	0.34337
x2	-0.012781	0.0060312	-2.1192	0.036857
x1:x2	-0.00010892	0.00017925	-0.6076	0.545
x2^2	9.7518e-07	7.5389e-07	1.2935	0.19917

```
Number of observations: 94, Error degrees of freedom: 89
```

```
Root Mean Squared Error: 4.1
```

```
R-squared: 0.751, Adjusted R-Squared 0.739
```

```
F-statistic vs. constant model: 67, p-value = 4.99e-26
```

Only the intercept and x2 term, which corresponds to the Weight variable, are significant at the 5% significance level.

Now, perform a stepwise regression with a constant model as the starting model and a linear model with interactions as the upper model.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0];
```

```
mdl = LinearModel.stepwise(X,MPG,[0 0 0],'upper',T)
```

```
1. Adding x2, FStat = 259.3087, pValue = 1.643351e-28
```

```
mdl =
```

```
Linear regression model:
```

$$y \sim 1 + x2$$

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	49.238	1.6411	30.002	2.7015e-49

x2 -0.0086119 0.0005348 -16.103 1.6434e-28

Number of observations: 94, Error degrees of freedom: 92

Root Mean Squared Error: 4.13

R-squared: 0.738, Adjusted R-Squared 0.735

F-statistic vs. constant model: 259, p-value = 1.64e-28

The results of the stepwise regression are consistent with the results of `LinearModel.fit` in the previous step.

Formula

A formula for model specification is a string of the form

`'Y ~ terms'`,

where

- *Y* is the response name.
- *terms* contains
 - Variable names
 - + means include the next variable
 - - means do not include the next variable
 - : defines an interaction, a product of terms
 - * defines an interaction **and all lower-order terms**
 - ^ raises the predictor to a power, exactly as in * repeated, so ^ includes lower order terms as well
 - () groups terms

Note Formulas include a constant (intercept) term by default. To exclude a constant term from the model, include -1 in the formula.

LinearModel.fit

For example,

'Y ~ A + B + C' means a three-variable linear model with intercept.

'Y ~ A + B + C - 1' is a three-variable linear model without intercept.

'Y ~ A + B + C + B^2' is a three-variable model with intercept and a B^2 term.

'Y ~ A + B^2 + C' is the same as the previous example because B^2 includes a B term.

'Y ~ A + B + C + A:B' includes an A*B term.

'Y ~ A*B + C' is the same as the previous example because $A*B = A + B + A:B$.

'Y ~ A*B*C - A:B:C' has all interactions among A, B, and C, except the three-way interaction.

'Y ~ A*(B + C + D)' has all linear terms, plus products of A with each of the other variables.

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k, where k is a positive integer	A, A ² , ..., A ^k
A+B	A, B
A*B	A, B, A*B
A:B	A*B only
-B	Do not include B
A*B+C	A, B, C, A*B
A+B+C+A:B	A, B, C, A*B

Wilkinson Notation	Factors in Standard Notation
A*B*C - A:B:C	A, B, C, A*B, A*C, B*C
A*(B + C)	A, B, C, A*B, A*C

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using -1.

Examples

Linear Regression Model of Matrix Data

Fit a linear model of the Hald data.

Load the data.

```
load hald
X = ingredients; % predictor variables
y = heat; % response
```

Fit a default linear model to the data.

```
mdl = LinearModel.fit(X,y)
```

```
mdl =
```

```
Linear regression model:
y ~ 1 + x1 + x2 + x3 + x4
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	62.405	70.071	0.8906	0.39913
x1	1.5511	0.74477	2.0827	0.070822
x2	0.51017	0.72379	0.70486	0.5009
x3	0.10191	0.75471	0.13503	0.89592
x4	-0.14406	0.70905	-0.20317	0.84407

Number of observations: 13, Error degrees of freedom: 8

Root Mean Squared Error: 2.45

R-squared: 0.982, Adjusted R-Squared 0.974

LinearModel.fit

F-statistic vs. constant model: 111, p-value = 4.76e-07

Linear Regression with Categorical Predictor and Nonlinear Model

Fit a model of a dataset array that contains a categorical predictor. Use a nonlinear response formula.

Load the carsmall data.

```
load carsmall
```

Construct a dataset containing continuous predictor variable `Weight`, nominal predictor variable `Year`, and response variable `MPG`.

```
ds = dataset(MPG,Weight);  
ds.Year = ordinal(Model_Year);
```

Create a fitted model of `MPG` as a function of `Year`, `Weight`, and `Weight2`. (You don't have to include `Weight` explicitly in your formula because it is a lower-order term of `Weight2`. For details, see "Definitions" on page 20-715.)

```
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2')
```

```
mdl =
```

Linear regression model:

```
MPG ~ 1 + Weight + Year + Weight^2
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	54.206	4.7117	11.505	2.6648e-19
Weight	-0.016404	0.0031249	-5.2493	1.0283e-06
Year_76	2.0887	0.71491	2.9215	0.0044137
Year_82	8.1864	0.81531	10.041	2.6364e-16
Weight^2	1.5573e-06	4.9454e-07	3.149	0.0022303

Number of observations: 94, Error degrees of freedom: 89

Root Mean Squared Error: 2.78
R-squared: 0.885, Adjusted R-Squared 0.88
F-statistic vs. constant model: 172, p-value = 5.52e-41

Simultaneously Specify the Variables and Use Formula

Simultaneously identify response and predictor variables and specify the model using formula in linear regression.

Load sample data.

```
load hospital
```

Fit a linear model with interaction terms to the data.

```
mdl = LinearModel.fit(hospital, 'Weight~1+Age*Sex*Smoker-Age:Sex:Smoker
```

```
mdl =
```

Linear regression model:

```
Weight ~ 1 + Sex*Age + Sex*Smoker + Age*Smoker
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	118.7	7.0718	16.785	6.821e-30
Sex_Male	68.336	9.7153	7.0339	3.3386e-10
Age	0.31068	0.18531	1.6765	0.09699
Smoker_1	3.0425	10.446	0.29127	0.77149
Sex_Male:Age	-0.49094	0.24764	-1.9825	0.05037
Sex_Male:Smoker_1	0.9509	3.8031	0.25003	0.80312
Age:Smoker_1	-0.07288	0.26275	-0.27737	0.7821

Number of observations: 100, Error degrees of freedom: 93

Root Mean Squared Error: 8.75

R-squared: 0.898, Adjusted R-Squared 0.892

F-statistic vs. constant model: 137, p-value = 6.91e-44

LinearModel.fit

The weight of the patients do not seem to differ significantly according to age, or the status of smoking, or interaction of these factors with gender at the 5% significance level.

Robust Linear Regression Model

Fit a linear regression model of the Hald data using robust fitting.

Load the data.

```
load hald
X = ingredients; % predictor variables
y = heat; % response
```

Fit a robust linear model to the data.

```
mdl = LinearModel.fit(X,y,'linear','RobustOpts','on')
```

```
mdl =
```

```
Linear regression model (robust fit):
  y ~ 1 + x1 + x2 + x3 + x4
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	60.09	75.818	0.79256	0.4509
x1	1.5753	0.80585	1.9548	0.086346
x2	0.5322	0.78315	0.67957	0.51596
x3	0.13346	0.8166	0.16343	0.87424
x4	-0.12052	0.7672	-0.15709	0.87906

Number of observations: 13, Error degrees of freedom: 8

Root Mean Squared Error: 2.65

R-squared: 0.979, Adjusted R-Squared 0.969

F-statistic vs. constant model: 94.6, p-value = 9.03e-07

Algorithms

The main fitting algorithm is QR decomposition. For robust fitting, the algorithm is `robustfit`.

Alternatives You can construct a model in a range of possible models using `LinearModel.stepwise`. However, you cannot use robust regression and stepwise regression together.

See Also `LinearModel` | `predict` | `LinearModel.stepwise`

Tutorials

- “Examine Quality and Adjust the Fitted Model” on page 9-17
- “Predict or Simulate Responses to New Data” on page 9-36
- “Linear Regression Workflow” on page 9-40

How To

- “Linear Regression” on page 9-7

NaiveBayes.fit

Purpose Create Naive Bayes classifier object by fitting training data

Syntax
`nb = NaiveBayes.fit(training, class)`
`nb = NaiveBayes.fit(..., 'param1',val1, 'param2',val2, ...)`

Description `nb = NaiveBayes.fit(training, class)` builds a `NaiveBayes` classifier object `nb`. `training` is an N-by-D numeric matrix of training data. Rows of `training` correspond to observations; columns correspond to features. `class` is a classing variable for `training` taking K distinct levels. Each element of `class` defines which class the corresponding row of `training` belongs to. `training` and `class` must have the same number of rows.

`nb = NaiveBayes.fit(..., 'param1',val1, 'param2',val2, ...)` specifies one or more of the following name/value pairs:

- `'Distribution'` – a string or a 1-by-D cell vector of strings, specifying which distributions `fit` uses to model the data. If the value is a string, `fit` models all the features using one type of distribution. `fit` can also model different features using different types of distributions. If the value is a cell vector, its `j`th element specifies the distribution `fit` uses for the `j`th feature. The available types of distributions are:

`'normal'` Normal (Gaussian) distribution.
(default)

`'kernel'` Kernel smoothing density estimate.

- 'mvmn' Multivariate multinomial distribution for discrete data. `fit` assumes each individual feature follows a multinomial model within a class. The parameters for a feature include the probabilities of all possible values that the corresponding feature can take.
- 'mn' Multinomial distribution for classifying the count-based data such as the bag-of-tokens model. In the bag-of-tokens model, the value of the j th feature is the number of occurrences of the j th token in this observation, so it must be a non-negative integer. When 'mn' is used, `fit` considers each observation as multiple trials of a multinomial distribution, and considers each occurrence of a token as one trial. The number of categories (bins) in this multinomial model is the number of distinct tokens, i.e., the number of columns of training.

- 'Prior' – The prior probabilities for the classes, specified as one of the following:

- 'empirical' (default) `fit` estimates the prior probabilities from the relative frequencies of the classes in training.
- 'uniform' The prior probabilities are equal for all classes.

NaiveBayes.fit

vector	A numeric vector of length K specifying the prior probabilities in the class order of <code>class</code> .
structure	A structure <code>S</code> containing class levels and their prior probabilities. <code>S</code> must have two fields: <ul style="list-style-type: none">• <code>S.prob</code>: A numeric vector of prior probabilities.▪ <code>S.class</code>: A vector of the same type as <code>class</code>, containing unique class levels indicating the class for the corresponding element of <code>prob</code>. <code>S.class</code> must contain all the K levels in <code>class</code>. It can also contain classes that do not appear in <code>class</code>. This can be useful if <code>training</code> is a subset of a larger training set. <code>fit</code> ignores any classes that appear in <code>S.class</code> but not in <code>class</code>.

If the prior probabilities don't sum to one, `fit` will normalize them.

- `'KSWidth'` – The bandwidth of the kernel smoothing window. The default is to select a default bandwidth automatically for each combination of feature and class, using a value that is optimal for a Gaussian distribution. You can specify the value as one of the following:

scalar	Width for all features in all classes.
row vector	1-by- D vector where the j th element is the bandwidth for the j th feature in all classes.
column vector	K -by-1 vector where the i th element specifies the bandwidth for all features in the i th class. K represents the number of class levels.

matrix K-by-D matrix M where $M(i, j)$ specifies the bandwidth for the j th feature in the i th class.

structure A structure S containing class levels and their bandwidths. S must have two fields:

- **S.width** – A numeric array of bandwidths specified as a row vector, or a matrix with D columns.
 - **S.class** – A vector of the same type as **class**, containing unique class levels indicating the class for the corresponding row of **width**.
- **'KSSupport'** – The regions where the density can be applied. It can be a string, a two-element vector as shown below, or a 1-by- D cell array of these values:

'unbounded' (default) The density can extend over the whole real line.

'positive' The density is restricted to positive values.

[L,U] A two-element vector specifying the finite lower bound L and upper bound U for the support of the density.

- **'KSType'** – The type of kernel smoother to use. It can be a string or a 1-by- D cell array of strings. Each string can be **'normal'** (default), **'box'**, **'triangle'**, or **'epanechnikov'**.

How To

- “Naive Bayes Classification” on page 12-36
- “Grouping Variables” on page 2-72

NonLinearModel.fit

Purpose Fit nonlinear regression model

Syntax

```
mdl = NonLinearModel.fit(ds,modelfun,beta0)
mdl = NonLinearModel.fit(X,y,modelfun,beta0)
mdl = NonLinearModel.fit(...,modelfun,beta0,Name,Value)
```

Description `mdl = NonLinearModel.fit(ds,modelfun,beta0)` fits the model specified by `modelfun` to variables in the dataset array `ds`, and returns the nonlinear model `mdl`. `NonLinearModel.fit` estimates model coefficients using an iterative procedure starting from the initial values in `beta0`.

`mdl = NonLinearModel.fit(X,y,modelfun,beta0)` fits a nonlinear regression model using the column vector `y` as a response variable and the columns of the matrix `X` as predictor variables.

`mdl = NonLinearModel.fit(...,modelfun,beta0,Name,Value)` fits a nonlinear regression model with additional options specified by one or more `Name, Value` pair arguments.

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors and response must be numeric.

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

X

Matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as `X`. Each entry in `y` is the response to the data in the corresponding row of `X`.

modelfun

Functional form of the model. Either a:

- Function handle `@modelfun` or `@(b,x)modelfun`, where
 - `b` is a coefficient vector with the same number of elements as `beta0`.
 - `x` is a matrix with the same number of columns as `X` or the data columns of `ds`.

`modelfun(b,x)` returns a column vector that contains the same number of rows as `x`. Each row of the vector is the result of evaluating `modelfun` on the corresponding row of `x`. In other words, `modelfun` is a vectorized function, one that operates on all data rows and returns all evaluations in one function call.

- String of the form

$$'y \sim f(b_1, b_2, \dots, b_k, x_1, x_2, \dots, x_k)'$$

f represents a scalar function of the scalar coefficient variables b_1, \dots, b_k and the scalar data variables x_1, \dots, x_k .

beta0

Numeric vector of coefficients for the `modelfun` nonlinear model. `NonLinearModel.fit` starts its search for optimal coefficients from `beta0`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

CoefficientNames

NonLinearModel.fit

Cell array of strings specifying the names of the model coefficients. `modelfun` gives the model.

Default: {'b1', 'b2', ..., 'bk'}

Exclude

Logical or numerical index vector indicating which observations to exclude from the fit. For example, to exclude observations 2 and 3 out of 6, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: []

Options

Structure as created by `statset` for controlling the iterative fitting procedure. The relevant fields are the nonempty fields in the structure returned by the call `statset('nlinfit')`.

Option	Meaning	Default
DerivStep	Relative difference used in finite difference derivative calculations. A positive scalar, or a vector of positive scalars the same size as the vector of parameters estimated by the Statistics Toolbox function using the options structure.	$\text{eps}^{(1/3)}$
Display	Amount of information displayed by the fitting algorithm. <ul style="list-style-type: none">'off' — Displays no information.'final' — Displays the final output.	'off'

Option	Meaning	Default
	<ul style="list-style-type: none"> 'iter' — Displays iterative output to the Command Window. 	
FunValCheck	String indicating to check for invalid values, such as NaN or Inf, from the model function.	'on'
MaxIter	Maximum number of iterations allowed. Positive integer.	200
RobustWgtFun	Weight function for robust fitting. Can also be a function handle that accepts a normalized residual as input and returns the robust weights as output. If you use a function handle, give a Tune constant. See “Robust Options” on page 20-735.	[]
Tune	Tuning constant used in robust fitting to normalize the residuals before applying the weight function. A positive scalar. Required if the weight function is specified as a function handle.	See “Robust Options” on page 20-735 for the default, which depends on RobustWgtFun.
ToIFun	Termination tolerance for the objective function value. Positive scalar.	1e-8
ToIX	Termination tolerance for the parameters. Positive scalar.	1e-8

Default: []

PredictorVars

Description of the variables that NonLinearModel.fit uses for fitting. Either a:

- Cell array of strings of variable names in the ds dataset array, or in the VarNames name-value pair

NonLinearModel.fit

- Vector of integer or logical indices into the variables in `ds` or the columns of `X`

Default: All variables in matrix `X`, or all variables except for the last in dataset array `ds`

ResponseVar

Variable that `NonLinearModel.fit` uses for response data. Either a:

- Variable name in `ds`
- Index of variable in `ds`

Default: Last column of dataset array `ds`

VarNames

Cell array of strings giving the variable names of the data, followed by the response variable name.

Default: { 'x1', 'x2', ..., 'xk', 'y' }

Weights

Vector of nonnegative weights or a function handle.

- If you specify a vector, then it must have N elements, where N is the number of rows in `ds` or `y`.
- If you specify a function handle, then the function must accept a vector of predicted response values as input, and return a vector of real positive weights as output.

Given weights, W , `NonLinearModel.fit` estimates the error variance at observation i by $MSE * (1/W(i))$, where MSE is the mean squared error.

Default: Vector of 1s

Output Arguments

mdl

Nonlinear model representing a least-squares fit of the response to the data. If the `Options` structure contains a nonempty `RobustWgtFun` field, the model is not a least-squares fit, but uses the `RobustWgtFun` robust fitting function.

Definitions

Robust Options

Weight Function	Equation	Default Tuning Constant
'andrews'	$w = (\text{abs}(r) < \pi) \cdot \sin(r) ./ r$	1.339
'bisquare' (default)	$w = (\text{abs}(r) < 1) \cdot (1 - r.^2).^2$	4.685
'cauchy'	$w = 1 ./ (1 + r.^2)$	2.385
'fair'	$w = 1 ./ (1 + \text{abs}(r))$	1.400
'huber'	$w = 1 ./ \max(1, \text{abs}(r))$	1.345
'logistic'	$w = \tanh(r) ./ r$	1.205
'talwar'	$w = 1 * (\text{abs}(r) < 1)$	2.795
'welsch'	$w = \exp(-(r.^2))$	2.985
[]	No robust fitting	—

Examples

Nonlinear Model from a Dataset Array

Create a nonlinear model for auto mileage based on the `carbig` data.

Load the data and create a nonlinear model.

```
load carbig
ds = dataset(Horsepower,Weight,MPG);
```

NonLinearModel.fit

```
modelfun = @(b,x)b(1) + b(2)*x(:,1).^b(3) + ...  
    b(4)*x(:,2).^b(5);  
beta0 = [-50 500 -1 500 -1];  
mdl = NonLinearModel.fit(ds,modelfun,beta0)
```

```
mdl =
```

Nonlinear regression model:

MPG ~ b1 + b2*Horsepower^b3 + b4*Weight^b5

Estimated Coefficients:

	Estimate	SE	tStat	pValue
b1	-49.383	119.97	-0.41164	0.68083
b2	376.43	567.05	0.66384	0.50719
b3	-0.78193	0.47168	-1.6578	0.098177
b4	422.37	776.02	0.54428	0.58656
b5	-0.24127	0.48325	-0.49926	0.61788

Number of observations: 392, Error degrees of freedom: 387

Root Mean Squared Error: 3.96

R-Squared: 0.745, Adjusted R-Squared 0.743

F-statistic vs. constant model: 283, p-value = 1.79e-113

Nonlinear Model from Matrix Data

Create a nonlinear model for auto mileage based on the carbig data.

Load the data and create a nonlinear model.

```
load carbig  
X = [Horsepower,Weight];  
y = MPG;  
modelfun = @(b,x)b(1) + b(2)*x(:,1).^b(3) + ...  
    b(4)*x(:,2).^b(5);  
beta0 = [-50 500 -1 500 -1];  
mdl = NonLinearModel.fit(X,y,modelfun,beta0)
```

```
mdl =
```

```
Nonlinear regression model:
```

$$y \sim b_1 + b_2 * x_1^{b_3} + b_4 * x_2^{b_5}$$

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
b1	-49.383	119.97	-0.41164	0.68083
b2	376.43	567.05	0.66384	0.50719
b3	-0.78193	0.47168	-1.6578	0.098177
b4	422.37	776.02	0.54428	0.58656
b5	-0.24127	0.48325	-0.49926	0.61788

```
Number of observations: 392, Error degrees of freedom: 387
```

```
Root Mean Squared Error: 3.96
```

```
R-Squared: 0.745, Adjusted R-Squared 0.743
```

```
F-statistic vs. constant model: 283, p-value = 1.79e-113
```

Adjust Fitting Options in the Nonlinear Model

Create a nonlinear model for auto mileage based on the `carbig` data. Strive for more accuracy by lowering the `TolFun` option, and observe the iterations by setting the `Display` option.

Load the data and create a nonlinear model.

```
load carbig
X = [Horsepower,Weight];
y = MPG;
modelfun = @(b,x)b(1) + b(2)*x(:,1).^b(3) + ...
    b(4)*x(:,2).^b(5);
beta0 = [-50 500 -1 500 -1];
```

Create options to lower `TolFun` and to report iterative display, and create a model using the options.

```
opts = statset('Display','iter','TolFun',1e-10);
```

NonLinearModel.fit

```
mdl = NonLinearModel.fit(X,y,modelfun,beta0,'Options',opts);
```

Iteration	SSE	Norm of Gradient	Norm of Step
0	1.82248e+06		
1	678600	788810	1691.07
2	616716	6.12739e+06	45.4738

122	6068.48	1.56393	0.629325
123	6068.48	1.13809	0.432543
124	6068.48	0.295962	0.297511

Iterations terminated: relative change in SSE less than OPTIONS.TolFun

Specify Nonlinear Regression Using Model String Syntax

Specify a nonlinear regression model for estimation using a function handle or model string syntax.

Load sample data.

```
S = load('reaction');  
X = S.reactants;  
y = S.rate;  
beta0 = S.beta;
```

Use a function handle to specify the Hougen-Watson model for the rate data.

```
mdl = NonLinearModel.fit(X,y,@hougen,beta0)
```

```
mdl =
```

```
Nonlinear regression model:  
y ~ hougen(b,X)
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
b1	1.2526	0.86701	1.4447	0.18654
b2	0.062776	0.043561	1.4411	0.18753
b3	0.040048	0.030885	1.2967	0.23089
b4	0.11242	0.075157	1.4957	0.17309
b5	1.1914	0.83671	1.4239	0.1923

Number of observations: 13, Error degrees of freedom: 8
Root Mean Squared Error: 0.193
R-Squared: 0.999, Adjusted R-Squared 0.998
F-statistic vs. zero model: 3.91e+03, p-value = 2.54e-13

Alternatively, you can use a string expression to specify the Hougén-Watson model for the rate data.

```
myfun = 'y~(b1*x2-x3/b5)/(1+b2*x1+b3*x2+b4*x3)';  
mdl2 = NonLinearModel.fit(X,y,myfun,beta0)
```

```
mdl2 =
```

Nonlinear regression model:

$$y \sim (b1*x2 - x3/b5)/(1 + b2*x1 + b3*x2 + b4*x3)$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
b1	1.2526	0.86701	1.4447	0.18654
b2	0.062776	0.043561	1.4411	0.18753
b3	0.040048	0.030885	1.2967	0.23089
b4	0.11242	0.075157	1.4957	0.17309
b5	1.1914	0.83671	1.4239	0.1923

Number of observations: 13, Error degrees of freedom: 8

NonLinearModel.fit

Root Mean Squared Error: 0.193
R-Squared: 0.999, Adjusted R-Squared 0.998
F-statistic vs. zero model: 3.91e+03, p-value = 2.54e-13

Estimate Nonlinear Regression Using Robust Fitting Options

Generate sample data from the nonlinear regression model

$$y = b_1 + b_2 \exp\{-b_3 x\} + \varepsilon,$$

where b_1 , b_2 , and b_3 are coefficients, and the error term is normally distributed with mean 0 and standard deviation 0.5.

```
modelfun = @(b,x)(b(1)+b(2)*exp(-b(3)*x));
```

```
rng('default') % for reproducibility  
b = [1;3;2];  
x = exprnd(2,100,1);  
y = modelfun(b,x) + normrnd(0,0.5,100,1);
```

Set robust fitting options.

```
opts = statset('nlinfit');  
opts.RobustWgtFun = 'bisquare';
```

Fit the nonlinear model using the robust fitting options. Here, use a string expression to specify the model.

```
b0 = [2;2;2];  
modelstr = 'y ~ b1 + b2*exp(-b3*x)';
```

```
mdl = NonLinearModel.fit(x,y,modelstr,b0,'Options',opts)
```

```
mdl =
```

```
Nonlinear regression model (robust fit):  
y ~ b1 + b2*exp( - b3*x)
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
b1	1.0218	0.07202	14.188	2.1344e-25
b2	3.6619	0.25429	14.401	7.974e-26
b3	2.9732	0.38496	7.7232	1.0346e-11

Number of observations: 100, Error degrees of freedom: 97

Root Mean Squared Error: 0.501

R-Squared: 0.807, Adjusted R-Squared 0.803

F-statistic vs. constant model: 203, p-value = 2.34e-35

Fit Nonlinear Regression Model Using Weights Function Handle

Load sample data.

```
S = load('reaction');  
X = S.reactants;  
y = S.rate;  
beta0 = S.beta;
```

Specify a function handle for observation weights. The function accepts the model fitted values as input, and returns a vector of weights.

```
a = 1; b = 1;  
weights = @(yhat) 1./((a + b*abs(yhat)).^2);
```

Fit the Hougen-Watson model to the rate data using the specified observation weights function.

```
mdl = NonLinearModel.fit(X,y,@hougen,beta0,'Weights',weights)
```

```
mdl =
```

```
Nonlinear regression model:  
y ~ hougen(b,X)
```

NonLinearModel.fit

Estimated Coefficients:

	Estimate	SE	tStat	pValue
b1	0.83085	0.58224	1.427	0.19142
b2	0.04095	0.029663	1.3805	0.20477
b3	0.025063	0.019673	1.274	0.23842
b4	0.080053	0.057812	1.3847	0.20353
b5	1.8261	1.281	1.4256	0.19183

Number of observations: 13, Error degrees of freedom: 8

Root Mean Squared Error: 0.037

R-Squared: 0.998, Adjusted R-Squared 0.998

F-statistic vs. zero model: 1.14e+03, p-value = 3.49e-11

Algorithms

NonLinearModel.fit uses the same fitting algorithm as nlinfit.

References

[1] Seber, G. A. F., and C. J. Wild. *Nonlinear Regression*. Hoboken, NJ: Wiley-Interscience, 2003.

[2] DuMouchel, W. H., and F. L. O'Brien. "Integrating a Robust Option into a Multiple Regression Computing Environment." *Computer Science and Statistics: Proceedings of the 21st Symposium on the Interface*. Alexandria, VA: American Statistical Association, 1989.

[3] Holland, P. W., and R. E. Welsch. "Robust Regression Using Iteratively Reweighted Least-Squares." *Communications in Statistics: Theory and Methods*, A6, 1977, pp. 813–827.

See Also

NonLinearModel | nlinfit

Related Examples

- “Examine Quality and Adjust the Fitted Model” on page 9-202
- “Predict or Simulate Responses to New Data” on page 9-206
- “Nonlinear Regression Workflow” on page 9-210

Concepts

- “Nonlinear Regression” on page 9-196

RegressionTree.fit

Purpose Binary decision tree for regression

Syntax
`tree = RegressionTree.fit(X,Y)`
`tree = RegressionTree.fit(X,Y,Name,Value)`

Description `tree = RegressionTree.fit(X,Y)` returns a regression tree based on the input variables (also known as predictors, features, or attributes) `X` and output (response) `Y`. `tree` is a binary tree where each branching node is split based on the values of a column of `X`.

`tree = RegressionTree.fit(X,Y,Name,Value)` fits a tree with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`. If you use one of the following five options, `tree` is of class `RegressionPartitionedModel`: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Otherwise, `tree` is of class `RegressionTree`.

Input Arguments

X

A matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

`RegressionTree.fit` considers NaN values in `X` as missing values. `RegressionTree.fit` does not use observations with all missing values for `X` the fit. `RegressionTree.fit` uses observations with some missing values for `X` to find splits on variables for which these observations have valid values.

Y

A numeric column vector with the same number of rows as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

`RegressionTree.fit` considers NaN values in `Y` to be missing values. `RegressionTree.fit` does not use observations with missing values for `Y` in the fit.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

CategoricalPredictors

List of categorical predictors. Pass `CategoricalPredictors` as one of:

- A numeric vector with indices from 1 to p , where p is the number of columns of X .
- A logical vector of length p , where a `true` entry means that the corresponding column of X is a categorical variable.
- `'all'`, meaning all predictors are categorical.
- A cell array of strings, where each element in the array is the name of a predictor variable. The names must match entries in the `PredictorNames` property.
- A character matrix, where each row of the matrix is a name of a predictor variable. Pad the names with extra blanks so each row of the character matrix has the same length.

Default: `[]`

crossval

If `'on'`, grows a cross-validated decision tree with 10 folds. You can use `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'` parameters to override this cross-validation setting. You can only use one of these four parameters (`'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`) at a time when creating a cross-validated tree.

RegressionTree.fit

Alternatively, cross-validate `tree` later using the `crossval` method.

Default: 'off'

cvpartition

A partition created with `cvpartition` to use in cross-validated tree. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout' and 'cvpartition'.

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout' and 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

MergeLeaves

When 'on', `RegressionTree` merges leaves that originate from the same parent node, and that give a sum of risk values greater or equal to the risk associated with the parent node. When 'off', `RegressionTree` does not merge leaves.

Default: 'on'

MinLeaf

Each leaf has at least `MinLeaf` observations per tree leaf. If you supply both `MinParent` and `MinLeaf`, `RegressionTree` uses the setting that gives larger leaves: $\text{MinParent} = \max(\text{MinParent}, 2 * \text{MinLeaf})$.

Default: 1

MinParent

Each branch node in the tree has at least `MinParent` observations. If you supply both `MinParent` and `MinLeaf`, `RegressionTree` uses the setting that gives larger leaves: $\text{MinParent} = \max(\text{MinParent}, 2 * \text{MinLeaf})$.

Default: 10

NVarToSample

Number of predictors to select at random for each split. Can be a positive integer or `'all'`, which means use all available predictors.

Default: `'all'`

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

Default: `{ 'x1', 'x2', ... }`

Prune

When `'on'`, `RegressionTree` computes the full tree and the optimal sequence of pruned subtrees. When `'off'` `RegressionTree` computes the full tree without pruning.

RegressionTree.fit

Default: 'on'

PruneCriterion

String with the pruning criterion, always 'error'.

Default: 'error'

ResponseName

Name of the response variable Y, a string.

Default: 'Y'

ResponseTransform

Function handle for transforming the raw response values (mean squared error). The function handle should accept a matrix of response values and return a matrix of the same size. The default string 'none' means $@(x)x$, or no transformation.

Add or change a ResponseTransform function by dot addressing:

```
tree.ResponseTransform = @function
```

Default: 'none'

SplitCriterion

Criterion for choosing a split, always the string 'MSE', meaning mean squared error.

Default: 'MSE'

Weights

Vector of observation weights. The length of `weights` is the number of rows in `X`.

Default: `ones(size(X,1),1)`

Output Arguments

tree

A regression tree object. You can use `tree` to predict the response of new data with the `predict` method.

Examples

Load the data in `carsmall.mat`, and make a regression tree to predict the mileage of cars based on their weights and numbers of cylinders:

```
load carsmall
tree = RegressionTree.fit([Weight, Cylinders],MPG,...
    'MinParent',20,...
    'PredictorNames',{'W','C'})
```

```
tree =
RegressionTree:
    PredictorNames: {'W' 'C'}
    CategoricalPredictors: []
    ResponseName: 'Y'
    ResponseTransform: 'none'
    NObservations: 94
```

Predict the mileage of a car that weighs 2200 lbs and has four cylinders:

```
predict(tree,[2200,4])
```

```
ans =
    29.6111
```

See Also

`predict`

fitdist

Purpose Fit probability distribution to data

Syntax

```
PD = fitdist(X, DistName)
[PDCA, GN, GL] = fitdist(X, DistName, 'By', GroupVar)
... = fitdist(..., param1, val1, param2, val2, ...)
```

Description *PD* = fitdist(*X*, *DistName*) fits the probability distribution specified by *DistName* to the data in the column vector *X*, and returns *PD*, an object representing the fitted distribution.

[*PDCA*, *GN*, *GL*] = fitdist(*X*, *DistName*, 'By', *GroupVar*) takes a grouping variable, *GroupVar*, fits the specified distribution to the data in *X* from each group, and returns *PDCA*, a cell array of the fitted probability distribution objects. *GroupVar* can also be a cell array of multiple grouping variables. *GN* is a cell array of group labels. *GL* is a cell array of grouping variable levels, with one column for each grouping variable. See “Grouping Variables” on page 2-72 for more information.

... = fitdist(..., *param1*, *val1*, *param2*, *val2*, ...) specifies optional parameter name/value pairs, as described in the Parameter/Values table. Parameter and value names are case insensitive.

Input Arguments

X A column vector of data.

Note Any NaN values in *X* are ignored by the fitting calculations. Additionally, any NaN values in the censoring vector or frequency vector will cause the corresponding values in *X* to be ignored by the fitting calculations.

DistName A string specifying a distribution. Choices are:

- 'kernel' — To fit a nonparametric kernel-smoothing distribution.

- Any of the following to fit a parametric distribution:
 - 'beta'
 - 'binomial'
 - 'birnbaumsaunders'
 - 'burr'
 - 'exponential'
 - 'extreme value' or 'ev'
 - 'gamma'
 - 'generalized extreme value' or 'gev'
 - 'generalized pareto' or 'gp'
 - 'inversegaussian'
 - 'logistic'
 - 'loglogistic'
 - 'lognormal'
 - 'nakagami'
 - 'negative binomial' or 'nbin'
 - 'normal'
 - 'poisson'
 - 'rayleigh'
 - 'rician'
 - 'tlocationscale'
 - 'weibull' or 'wbl'

For more information on these parametric distributions, see Appendix B, “Distribution Reference”.

GroupVar

A grouping variable or a cell array of multiple grouping variables. For more information on grouping variables, see “Grouping Variables” on page 2-72.

Parameter	Values
'censoring	<p>A Boolean vector the same size as X, containing 1s when the corresponding elements in X are right-censored observations and 0s when the corresponding elements are exact observations. Default is a vector of 0s.</p> <hr/> <p>Note Any NaN values in this censoring vector are ignored by the fitting calculations. Additionally, any NaN values in X or the frequency vector will cause the corresponding values in the censoring vector to be ignored by the fitting calculations.</p> <hr/>
'frequency	<p>A vector the same size as X, containing nonnegative integers specifying the frequencies for the corresponding elements in X. Default is a vector of 1s.</p> <hr/> <p>Note Any NaN values in this frequency vector are ignored by the fitting calculations. Additionally, any NaN values in X or the censoring vector will cause the corresponding values in the frequency vector to be ignored by the fitting calculations.</p> <hr/>

Parameter	Values
'options'	A structure created by the <code>statset</code> function to specify control parameters for the iterative fitting algorithm.
'n'	For 'binomial' distributions only, a positive integer specifying the N parameter (number of trials).
'theta'	For 'generalized pareto' distributions only, value specifying the theta (threshold) parameter for the generalized Pareto distribution. Default is 0.
'kernel'	For 'kernel' distributions only, a string specifying the type of kernel smoother to use. Choices are: <ul style="list-style-type: none"> • 'normal' (default) • 'box' • 'triangle' • 'epanechnikov'
'support'	For 'kernel' distributions only, any of the following to specify the support: <ul style="list-style-type: none"> • 'unbounded' — Default. If the density can extend over the whole real line. • 'positive' — To restrict it to positive values. • A two-element vector giving finite lower and upper limits for the support of the density.
'width'	For 'kernel' distributions only, a value specifying the bandwidth of the kernel smoothing window. The default is optimal for estimating normal densities, but you may want to choose a smaller value to reveal features such as multiple modes.

Output Arguments

<i>PD</i>	An object in either the <code>ProbDistUnivKernel</code> class or the <code>ProbDistUnivParam</code> class, which are derived from the <code>ProbDist</code> class.
<i>PDCA</i>	A cell array of the fitted probability distribution objects.
<i>GN</i>	A cell array of group labels.
<i>GL</i>	A cell array of grouping variable levels, with one column for each grouping variable.

Examples

Creating a `ProbDistUnivKernel` Object

- 1 Load a MAT-file, included with the Statistics Toolbox software, which contains `MPG`, a column vector of data.

```
load carsmall
```

- 2 Create a `ProbDistUnivKernel` object by fitting a nonparametric kernel-smoothing distribution to the data:

```
ksd = fitdist(MPG,'kernel')
```

```
ksd =
```

```
kernel distribution
```

```
Kernel = normal  
Bandwidth = 4.11428  
Support = unbounded
```

Creating a `ProbDistUnivParam` Object

- 1 Load a MAT-file, included with the Statistics Toolbox software, which contains `MPG`, a column vector of data, and `Origin`, a cell array of seven grouping variables.

```
load carsmall
```

- 2 Create a cell array of `ProbDistUnivParam` objects by fitting a parametric distribution, namely a Weibull distribution, to the data, and also grouping the data. Since there is only one car from Italy, `fitdist` will return an error, since you cannot fit a distribution to a single observation.

```
wd = fitdist(MPG,'weibull','by',Origin)
```

Algorithms

The `fitdist` function fits most distributions using maximum likelihood. Two exceptions are the normal and lognormal distributions with uncensored data. For the uncensored normal distribution, the estimated value of the sigma parameter is the square root of the unbiased estimate of the variance. For the uncensored lognormal distribution, the estimated value of the sigma parameter is the square root of the unbiased estimate of the variance of the log of the data.

References

- [1] Johnson, N. L., S. Kotz, and N. Balakrishnan. *Continuous Univariate Distributions*. Vol. 1, Hoboken, NJ: Wiley-Interscience, 1993.
- [2] Johnson, N. L., S. Kotz, and N. Balakrishnan. *Continuous Univariate Distributions*. Vol. 2, Hoboken, NJ: Wiley-Interscience, 1994.
- [3] Bowman, A. W., and A. Azzalini. *Applied Smoothing Techniques for Data Analysis*. New York: Oxford University Press, 1997.

Alternatives

`dffitool` — Opens a graphical user interface for displaying fit distributions to data, or for fitting distributions to your data and displaying them over plots of the empirical distributions, by importing data from the workspace.

See Also

`disttool` | `randtool` | `statset` | `ProbDist` | `ProbDistUnivKernel` | `ProbDistUnivParam`

How To

- Appendix B, “Distribution Reference”
- “Grouping Variables” on page 2-72

Purpose	Fitted ensemble for classification or regression
Syntax	<pre>ens = fitensemble(X,Y,method,nlearn,learners) ens = fitensemble(X,Y,method,nlearn,learners,Name,Value)</pre>
Description	<p><code>ens = fitensemble(X,Y,method,nlearn,learners)</code> creates an ensemble model that predicts responses to data. The ensemble consists of models listed in <code>learners</code>.</p> <p><code>ens = fitensemble(X,Y,method,nlearn,learners,Name,Value)</code> creates an ensemble model with additional options specified by one or more <code>Name, Value</code> pair arguments. You can specify several name-value pair arguments in any order as <code>Name1, Value1, ..., NameN, ValueN</code>.</p>
Tips	<ul style="list-style-type: none">• If <code>X</code> has categorical predictors with many levels, use 'GentleBoost' or 'LogitBoost' for binary classification. Using other algorithms in this case would likely cause long training times and can exhaust memory.
Input Arguments	<p>X</p> <p>Matrix of predictor values. Each column of <code>X</code> represents one variable, and each row represents one observation.</p> <p>Y</p> <p>For classification, <code>Y</code> is a categorical variable, character array, or cell array of strings. Each row of <code>Y</code> represents the classification of the corresponding row of <code>X</code>.</p> <p>For regression, <code>Y</code> is a numeric column vector with the same number of rows as <code>X</code>. Each entry in <code>Y</code> is the response to the data in the corresponding row of <code>X</code>.</p> <p>method</p> <p>Case-insensitive string consisting of one of the following.</p> <ul style="list-style-type: none">• For classification with two classes:

- 'AdaBoostM1'
- 'LogitBoost'
- 'GentleBoost'
- 'RobustBoost' (requires an Optimization Toolbox license)
- 'LPBoost' (requires an Optimization Toolbox license)
- 'TotalBoost' (requires an Optimization Toolbox license)
- 'RUSBoost'
- 'Subspace'
- 'Bag'
- For classification with three or more classes:
 - 'AdaBoostM2'
 - 'LPBoost' (requires an Optimization Toolbox license)
 - 'TotalBoost' (requires an Optimization Toolbox license)
 - 'RUSBoost'
 - 'Subspace'
 - 'Bag'
- For regression:
 - 'LSBoost'
 - 'Bag'

'Bag' applies to all methods. So when you use 'Bag', indicate whether you want a classifier or regressor with the `type` name-value pair set to 'classification' or 'regression'.

nlearn

Number of ensemble learning cycles, a positive integer (or the string 'AllPredictorCombinations', see the next paragraph). At every training cycle, `fitensemble` loops over all learner templates in

learners and trains one weak learner for every template. The total number of trained learners in `ens` is `nlearn*numel(learners)`.

If you set `method` to `'Subspace'`, you can set `nlearn` to `'AllPredictorCombinations'`. With this setting, `fitensemble` constructs learners for all possible combinations of predictors taken `NPredToSample` at a time. This gives a total of `nchoosek(size(X,2),NPredToSample)` learners in the ensemble. You can use only one learner template for this setting.

`nlearn` for ensembles can vary from a few dozen to a few thousand. Usually, an ensemble with a good predictive power needs from a few hundred to a few thousand weak learners. You do not have to train an ensemble for that many cycles at once. You can start by growing a few dozen learners, inspect the ensemble performance and, if necessary, train more weak learners using the `resume` method of the ensemble.

learners

One of the following:

- A string with the name of a weak learner:
 - `'Discriminant'` (applies only to `'Subspace'`)
 - `'KNN'` (applies only to `'Subspace'`)
 - `'tree'` (applies to all methods except `'Subspace'`)
- A single weak learner template you create with `ClassificationTree.template`, `RegressionTree.template`, `ClassificationKNN.template`, or `ClassificationDiscriminant.template`.
- A cell array of weak learner templates. Usually you should supply only one weak learner template.

Ensemble performance depends on the parameters of the weak learners, and you can get poor performance using weak learners with default parameters. Specify the parameters for the weak learners in the template. Specify parameters for the ensemble in the `fitensemble` name-value pairs.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

All Ensembles:

CategoricalPredictors

List of categorical predictors. Pass `CategoricalPredictors` as one of:

- A numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.
- A logical vector of length `p`, where a `true` entry means that the corresponding column of `X` is a categorical variable.
- 'all', meaning all predictors are categorical.
- A cell array of strings, where each element in the array is the name of a predictor variable. The names must match entries in the `PredictorNames` property.
- A character matrix, where each row of the matrix is the name of a predictor variable. The names must match entries in the `PredictorNames` property. Pad the names with extra blanks so each row of the character matrix has the same length.

You can set `CategoricalPredictors` for these learners:

- 'Tree'
- 'KNN', when all predictors are categorical

Default: []

crossval

If 'on', grows a cross-validated learner with 10 folds. You can use 'kfold', 'holdout', 'leaveout', or 'cvpartition' parameters to

override this cross-validation setting. You can only use one of these four parameters ('kfold', 'holdout', 'leaveout', or 'cvpartition') at a time when creating a cross-validated learner.

Default: 'off'

cvpartition

Partition created with `cvpartition` to use in a cross-validated learner. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

fresample

Fraction of the training set to be selected by resampling for every weak learner. A numeric scalar from 0 to 1. This parameter has no effect unless you grow an ensemble by bagging or set 'resample' to 'on'. The default setting is the one used most often for an ensemble grown by resampling.

Default: 1

holdout

Holdout validation tests the specified fraction of the data, and uses the remaining data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated learner: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

kfold

Number of folds to use in a cross-validated learner, a positive integer. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

NPredToSample

Number of predictors in each random subspace learner, a positive integer from 1 to `size(X,2)`.

Default: 1

nprint

Printout frequency, a positive integer scalar. Set to 'off' for no printout. Use this parameter to track how many weak learners have been trained so far. This is useful when you train ensembles with many learners on large datasets. If you use one of the cross-validation options, this parameter defines the printout frequency per number of cross-validation folds.

Default: 'off'

PredictorNames

Cell array of names for the predictor variables, in the order in which they appear in `X`.

Default: {'x1', 'x2', ...}

replace

'on' or 'off'. If 'on', sample with replacement. If 'off', sample without replacement. This parameter has no effect unless you grow an ensemble by bagging or set `resample` to 'on'. If you set `resample` to 'on' and `replace` to 'off', `fitensemble` samples training observations assuming uniform weights, and boosts by reweighting observations.

Default: 'on'

resample

'on' or 'off'. If 'on', grow an ensemble by resampling, with the resampling fraction given by `fresample`, and sampling with or without replacement given by `replace`.

- Boosting — When 'off', the boosting algorithm reweights observations at every learning iteration. When 'on', the algorithm samples training observations using updated weights as the multinomial sampling probabilities.
- Bagging — You can use only the default value of this parameter ('on').

Default: 'off' for boosting, 'on' for bagging

ResponseName

Name of the response variable Y , a string.

Default: 'Y'

type

String, either 'classification' or 'regression'. Specify type when the method is 'bag'.

weights

Vector of observation weights. The length of `weights` is the number of rows in X .

Default: `ones(size(X,1),1)`

Classification Ensembles:**classnames**

Array of class names. Specify a data type the same as exists in Y .

Default: Class names that exist in Y

cost

Square matrix C , where $C(i, j)$ is the cost of classifying a point into class j if its true class is i . Alternatively, `cost` can be a structure S having two fields: `S.ClassNames` containing the group names as a categorical variable, character array, or cell array of strings; and `S.ClassificationCosts` containing the cost matrix C .

Default: $C(i, j) = 1$ if $i \neq j$, and $C(i, j) = 0$ if $i = j$

prior

Prior probabilities for each class. Specify as one of:

- A string:
 - 'empirical' determines class probabilities from class frequencies in Y . If you pass observation weights, they are used to compute the class probabilities.
 - 'uniform' sets all class probabilities equal.
- A vector (one scalar value for each class)
- A structure S with two fields:
 - `S.ClassNames` containing the class names as a categorical variable, character array, or cell array of strings
 - `S.ClassProbs` containing a vector of corresponding probabilities

If you set values for both `weights` and `prior`, the `weights` are renormalized to add up to the value of the prior probability in the respective class.

Default: 'empirical'

AdaBoostM1, AdaBoostM2, LogitBoost, GentleBoost, RUSBoost, and LSBoost:

LearnRate

Learning rate for shrinkage, a numeric scalar from 0 to 1. If you set the learning rate to less than 1, the ensemble requires more learning iterations but often achieves a better accuracy. 0.1 is a popular choice for an ensemble grown with shrinkage.

Default: 1

RUSBoost:**RatioToSmallest**

Either a numeric scalar or vector with K elements when there are K classes. Every element of this vector is the sampling proportion for this class with respect to the class with fewest observations in Y . If you pass a scalar, fitensemble uses this sampling proportion for all classes. For example, suppose you have class A with 100 observations and class B with 10 observations. If you pass [2 1] for 'RatioToSmallest', every learner in the ensemble is trained on 20 observations of class A and 10 observations of class B. If you pass 2 or [2 2], every learner is trained on 20 observations of class A and 20 observations of class B. If you pass 'ClassNames', fitensemble matches elements in the array of class names to elements in this vector.

Default: ones(K ,1)

LPBoost and TotalBoost:**MarginPrecision**

Margin precision, a numeric scalar between 0 and 1. MarginPrecision affects the number of boosting iterations required for conversion. Use a small value to grow an ensemble with many learners, and use a large value to grow an ensemble with few learners.

Default: 0.01

RobustBoost:

RobustErrorGoal

Target classification error for **RobustBoost**, a numeric scalar from 0 to 1. Usually there is an optimal range for this parameter for your training data. If you set the error goal too low or too high, **RobustBoost** can produce a model with poor classification accuracy.

Default: 0.1

RobustMarginSigma

Spread of the distribution of classification margins over the training set for **RobustBoost**, a numeric positive scalar. You should consult literature on **RobustBoost** before setting this parameter

Default: 0.1

RobustMaxMargin

Maximal classification margin for **RobustBoost** in the training set, a nonnegative numeric scalar. **RobustBoost** minimizes the number of observations in the training set with classification margins below **RobustMaxMargin**.

Default: 0

Output Arguments

ens

Ensemble object for predicting characteristics. The class of **ens** depends on settings. In the following table, cross-validation names are **crossval**, **kfold**, **holdout**, **leaveout**, and **cvpartition**.

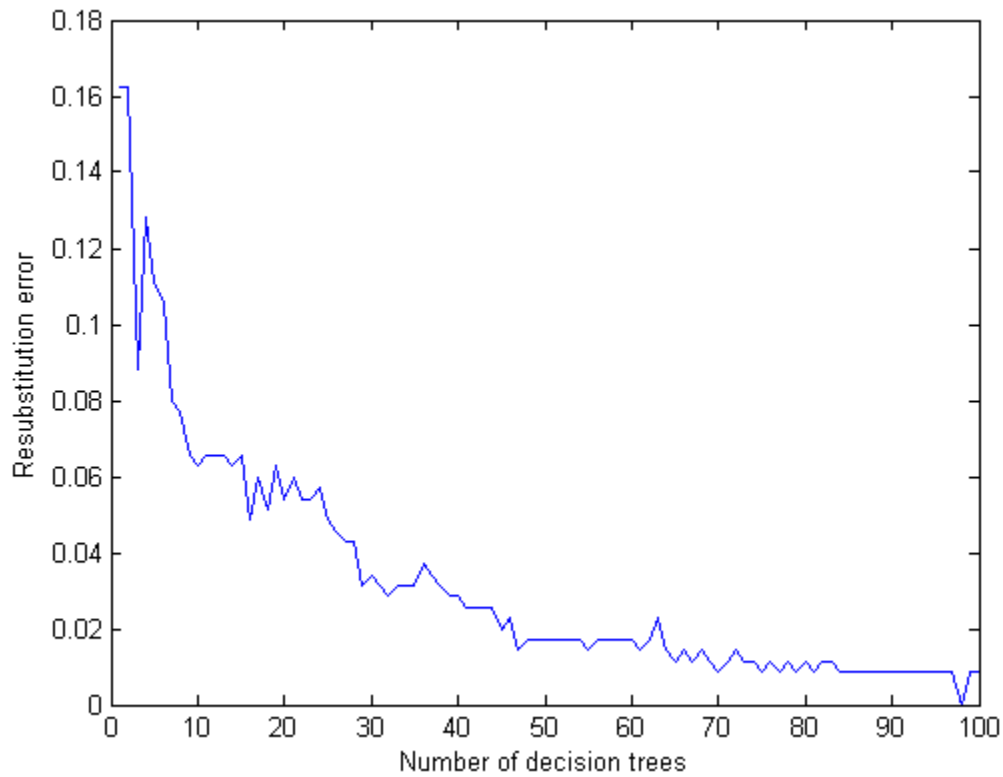
Settings	Class
resample name-value pair is 'off', and you don't set a cross-validation name-value pair.	ClassificationEnsemble
resample name-value pair is 'off', and you don't set a cross-validation name-value pair.	RegressionEnsemble
resample name-value pair is 'on', type is 'classification', and you don't set a cross-validation name-value pair.	ClassificationBaggedEnsemble
resample name-value pair is 'on', type is 'regression', and you don't set a cross-validation name-value pair.	RegressionBaggedEnsemble
method is a classification method, and you set a cross-validation name-value pair.	ClassificationPartitionedEnsemble
method is a regression method, and you set a cross-validation name-value pair.	RegressionPartitionedEnsemble

Examples

Train a boosting ensemble, and inspect the resubstitution loss:

```
load ionosphere;
ada = fitensemble(X,Y,'AdaBoostM1',100,'tree');
plot(resubLoss(ada,'mode','cumulative'));
xlabel('Number of decision trees');
ylabel('Resubstitution error');
```

fitensemble



Train a regression ensemble to predict car mileage based on the number of cylinders, engine displacement, horsepower, and weight. Predict the mileage for a four-cylinder car with a 200 cubic inch displacement, 150 horsepower, and weighing 3000 lbs.

```
load carsmall
X = [Cylinders,Displacement,Horsepower,Weight];
xnames = {'Cylinders','Displacement','Horsepower','Weight'};
t = RegressionTree.template('Surrogate','on');
rens = fitensemble(X,MPG,'LSBoost',100,t,'PredictorNames',xnames)

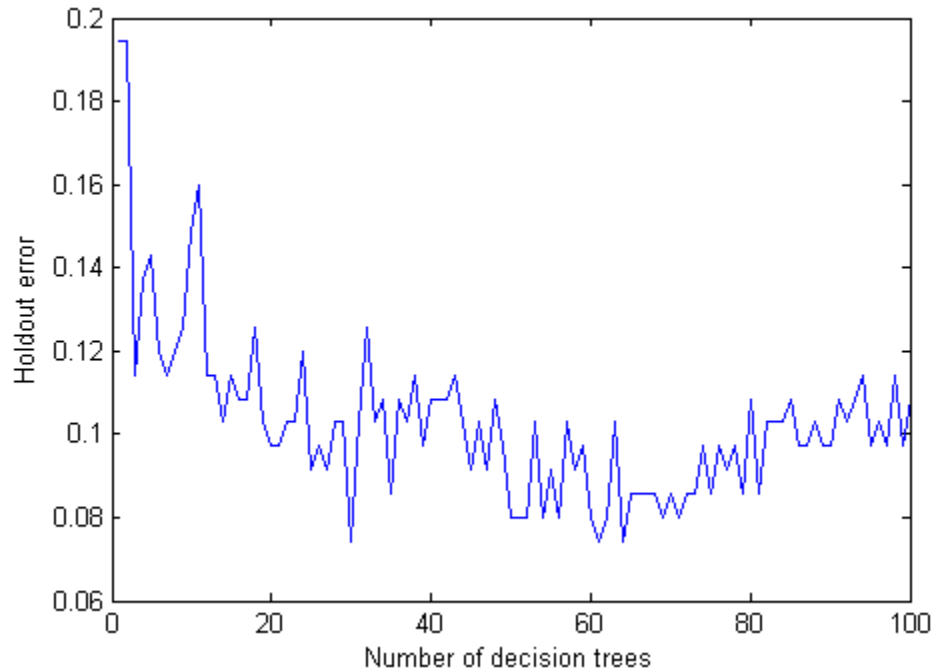
rens =
classreg.learning.regr.ReggressionEnsemble:
    PredictorNames: {'Cylinders' 'Displacement' 'Horsepower' 'Weight'}
    CategoricalPredictors: []
    ResponseName: 'Y'
    ResponseTransform: 'none'
    NObservations: 94
    NTrained: 100
    Method: 'LSBoost'
    LearnerNames: {'Tree'}
    ReasonForTermination: [1x77 char]
    FitInfo: [100x1 double]
    FitInfoDescription: [2x83 char]
    Regularization: []

predict(rens,[4 200 150 3000])

ans =
    20.4982
```

Train and estimate the generalization error on a holdout sample:

```
load ionosphere;
ada = fitensemble(X,Y,'AdaBoostM1',100,'Tree',...
    'holdout',0.5);
plot(kfoldLoss(ada,'mode','cumulative'));
xlabel('Number of decision trees');
ylabel('Holdout error');
```



Algorithms

For details of boosting and bagging algorithms, see “Ensemble Algorithms” on page 13-141.

See Also

`ClassificationEnsemble` | `RegressionEnsemble` |
`ClassificationBaggedEnsemble` | `RegressionBaggedEnsemble`
| `ClassificationPartitionedEnsemble`
| `RegressionPartitionedEnsemble` |
`ClassificationDiscriminant.template` |
`ClassificationKNN.template` | `ClassificationTree.template`
| `RegressionTree.template`

How To

- “Supervised Learning (Machine Learning) Workflow and Algorithms” on page 13-2

- “Ensemble Methods” on page 13-54

categorical.flipdim

Purpose Flip categorical array along specified dimension

Syntax `B = flipdim(A,dim)`

Description `B = flipdim(A,dim)` returns the categorical array `A` with dimension `dim` flipped.

See Also `flip1r` | `flipud` | `permute` | `rot90`

Purpose Flip categorical matrix in left/right direction

Syntax `B = fliplr(A)`

Description `B = fliplr(A)` returns the 2-D categorical matrix `A` with rows preserved and columns flipped in the left/right direction.

See Also `flipdim` | `flipud` | `permute` | `rot90`

categorical.flipud

Purpose Flip categorical matrix in up/down direction

Syntax `B = flipud(A)`

Description `B = flipud(A)` returns the 2-D categorical matrix `A` with rows preserved and columns flipped in the up/down direction.

See Also `flipdim` | `fliplr` | `permute` | `rot90`

Purpose F probability density function

Syntax $Y = \text{fpdf}(X, V1, V2)$

Description $Y = \text{fpdf}(X, V1, V2)$ computes the F pdf at each of the values in X using the corresponding numerator degrees of freedom $V1$ and denominator degrees of freedom $V2$. X , $V1$, and $V2$ can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. $V1$ and $V2$ parameters must contain real positive values, and the values in X must lie on the interval $[0 \infty)$.

The probability density function for the F distribution is

$$y = f(x | v_1, v_2) = \frac{\Gamma\left[\frac{(v_1 + v_2)}{2}\right]}{\Gamma\left(\frac{v_1}{2}\right)\Gamma\left(\frac{v_2}{2}\right)} \left(\frac{v_1}{v_2}\right)^{\frac{v_1}{2}} \frac{x^{\frac{v_1-2}{2}}}{\left[1 + \left(\frac{v_1}{v_2}\right)x\right]^{\frac{v_1+v_2}{2}}}$$

Examples

$y = \text{fpdf}(1:6, 2, 2)$

$y =$
0.2500 0.1111 0.0625 0.0400 0.0278 0.0204

$z = \text{fpdf}(3, 5:10, 5:10)$

$z =$
0.0689 0.0659 0.0620 0.0577 0.0532 0.0487

See Also

pdf | fcdf | finv | fstat | frnd

How To

- “F Distribution” on page B-38

fracfact

Purpose Fractional factorial design

Syntax
`X = fracfact(gen)`
`[X,conf] = fracfact(gen)`
`[X,conf] = fracfact(gen,Name,Value)`

Description `X = fracfact(gen)` creates the two-level fractional factorial design defined by the generator string `gen`.

`[X,conf] = fracfact(gen)` returns a cell array of strings containing the confounding pattern for the design.

`[X,conf] = fracfact(gen,Name,Value)` creates a fractional factorial designs with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

gen

Either a cell array of strings where each cell contains one “word,” or a string consisting of “words” separated by spaces. “Words” consist of case-sensitive letters or groups of letters, where 'a' represents string 1, 'b' represents string 2, ..., 'A' represents string 27, ..., 'Z' represents string 52.

Each word defines how the corresponding factor’s levels are defined as products of generators from a 2^K full-factorial design. K is the number of letters of the alphabet in `gen`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

FactorNames

Cell array specifying the name for each factor.

Default: {'X1', 'X2', ...}

MaxInt

Positive integer setting the maximum level of interaction to include in the confounding output.

Default: 2

Output Arguments

X

The two-level fractional factorial design. X is a matrix of size N-by-P, where

- $N = 2^K$, where K is the number of letters of the alphabet in gen.
- P is the number of words in gen.

Because X is a two-level design, the components of X are -1 . For the meaning of X, see “Fractional Factorial Designs” on page 15-5.

conf

Cell array of strings containing the confounding pattern for the design.

Examples

Generate a fractional factorial design for four variables, where the fourth variable is the product of the first three:

```
x = fracfact('a b c abc')
```

```
x =
    -1    -1    -1    -1
    -1    -1     1     1
    -1     1    -1     1
    -1     1     1    -1
     1    -1    -1     1
     1    -1     1    -1
     1     1    -1    -1
     1     1     1     1
```

fracfact

Find generators for a six-factor design that uses four factors and achieves resolution IV using fracfactgen. Use the result to specify the design:

```
generators = fracfactgen('a b c d e f',4, ... % 4 factors  
4) % resolution 4
```

```
generators =  
'a'  
'b'  
'c'  
'd'  
'bcd'  
'acd'
```

```
x = fracfact(generators)
```

```
x =  
-1 -1 -1 -1 -1 -1  
-1 -1 -1 1 1 1  
-1 -1 1 -1 1 1  
-1 -1 1 1 -1 -1  
-1 1 -1 -1 1 -1  
-1 1 -1 1 -1 1  
-1 1 1 1 1 -1  
1 -1 -1 -1 -1 1  
1 -1 -1 1 1 -1  
1 -1 1 -1 1 -1  
1 -1 1 1 -1 1  
1 1 -1 -1 1 1  
1 1 -1 1 -1 -1  
1 1 1 -1 -1 -1  
1 1 1 1 1 1
```

References

[1] Box, G. E. P., W. G. Hunter, and J. S. Hunter. *Statistics for Experimenters*. Hoboken, NJ: Wiley-Interscience, 1978.

See Also

ff2n | fracfactgen | fullfact | hadamard

How To

• “Fractional Factorial Designs” on page 15-5

fracfactgen

Purpose Fractional factorial design generators

Syntax

```
generators = fracfactgen(terms)
generators = fracfactgen(terms,k)
generators = fracfactgen(terms,k,R)
generators = fracfactgen(terms,k,R,basic)
```

Description `generators = fracfactgen(terms)` uses the Franklin-Bailey algorithm to find generators for the smallest two-level fractional-factorial design for estimating linear model terms specified by `terms`. `terms` is a string consisting of words formed from the 52 case-sensitive letters a-Z, separated by spaces. Use 'a' - 'z' for the first 26 factors, and, if necessary, 'A' - 'Z' for the remaining factors. For example, `terms = 'a b c ab ac'`. Single-character words indicate main effects to be estimated; multiple-character words indicate interactions. Alternatively, `terms` is an m -by- n matrix of 0s and 1s where m is the number of model terms to be estimated and n is the number of factors. For example, if `terms` contains rows `[0 1 0 0]` and `[1 0 0 1]`, then the factor `b` and the interaction between factors `a` and `d` are included in the model. `generators` is a cell array of strings with one generator per cell. Pass `generators` to `fracfact` to produce the fractional-factorial design and corresponding confounding pattern.

`generators = fracfactgen(terms,k)` returns generators for a two-level fractional-factorial design with 2^k -runs, if possible. If `k` is `[]`, `fracfactgen` finds the smallest design.

`generators = fracfactgen(terms,k,R)` finds a design with resolution `R`, if possible. The default resolution is 3.

A design of *resolution R* is one in which no n -factor interaction is confounded with any other effect containing less than $R - n$ factors. Thus a resolution III design does not confound main effects with one another but may confound them with two-way interactions, while a resolution IV design does not confound either main effects or two-way interactions but may confound two-way interactions with each other.

If `fracfactgen` is unable to find a design at the requested resolution, it tries to find a lower-resolution design sufficient to calibrate the model.

If it is successful, it returns the generators for the lower-resolution design along with a warning. If it fails, it returns an error.

`generators = fracfactgen(terms,k,R,basic)` also accepts a vector `basic` specifying the indices of factors that are to be treated as basic. These factors receive full-factorial treatments in the design. The default includes factors that are part of the highest-order interaction in `terms`.

Examples

Suppose you wish to determine the effects of four two-level factors, for which there may be two-way interactions. A full-factorial design would require $2^4 = 16$ runs. The `fracfactgen` function finds generators for a resolution IV (separating main effects) fractional-factorial design that requires only $2^3 = 8$ runs:

```
generators = fracfactgen('a b c d',3,4)
generators =
  'a'
  'b'
  'c'
  'abc'
```

The more economical design and the corresponding confounding pattern are returned by `fracfact`:

```
[dfF,confounding] = fracfact(generators)
dfF =
  -1  -1  -1  -1
  -1  -1   1   1
  -1   1  -1   1
  -1   1   1  -1
   1  -1  -1   1
   1  -1   1  -1
   1   1  -1  -1
   1   1   1   1
confounding =
  'Term'      'Generator'    'Confounding'
  'X1'        'a'             'X1'
  'X2'        'b'             'X2'
```

fracfactgen

'X3'	'c'	'X3'
'X4'	'abc'	'X4'
'X1*X2'	'ab'	'X1*X2 + X3*X4'
'X1*X3'	'ac'	'X1*X3 + X2*X4'
'X1*X4'	'bc'	'X1*X4 + X2*X3'
'X2*X3'	'bc'	'X1*X4 + X2*X3'
'X2*X4'	'ac'	'X1*X3 + X2*X4'
'X3*X4'	'ab'	'X1*X2 + X3*X4'

The confounding pattern shows, for example, that the two-way interaction between X1 and X2 is confounded by the two-way interaction between X3 and X4.

References

[1] Box, G. E. P., W. G. Hunter, and J. S. Hunter. *Statistics for Experimenters*. Hoboken, NJ: Wiley-Interscience, 1978.

See Also

fracfact | hadamard

How To

- “Fractional Factorial Designs” on page 15-5

Purpose

Friedman's test

Syntax

```
p = friedman(X, reps)
p = friedman(X, reps, displayopt)
[p, table] = friedman(...)
[p, table, stats] = friedman(...)
```

Description

`p = friedman(X, reps)` performs the nonparametric Friedman's test to compare column effects in a two-way layout. Friedman's test is similar to classical balanced two-way ANOVA, but it tests only for column effects after adjusting for possible row effects. It does not test for row effects or interaction effects. Friedman's test is appropriate when columns represent treatments that are under study, and rows represent nuisance effects (blocks) that need to be taken into account but are not of any interest.

The different columns of `X` represent changes in a factor A. The different rows represent changes in a blocking factor B. If there is more than one observation for each combination of factors, input `reps` indicates the number of replicates in each "cell," which must be constant.

The matrix below illustrates the format for a set-up where column factor A has three levels, row factor B has two levels, and there are two replicates (`reps=2`). The subscripts indicate row, column, and replicate, respectively.

$$\begin{bmatrix} x_{111} & x_{121} & x_{131} \\ x_{112} & x_{122} & x_{132} \\ x_{211} & x_{221} & x_{231} \\ x_{212} & x_{222} & x_{232} \end{bmatrix}$$

Friedman's test assumes a model of the form

$$x_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$$

where μ is an overall location parameter, α_i represents the column effect, β_j represents the row effect, and ε_{ijk} represents the error. This test ranks the data within each level of B, and tests for a difference across levels of A. The `p` that `friedman` returns is the p value for the null hypothesis that $\alpha_i = 0$. If the p value is near zero, this casts doubt on the null hypothesis. A sufficiently small p value suggests that at least one column-sample median is significantly different than the others; i.e., there is a main effect due to factor A. The choice of a critical p value to determine whether a result is “statistically significant” is left to the researcher. It is common to declare a result significant if the p value is less than 0.05 or 0.01.

`friedman` also displays a figure showing an ANOVA table, which divides the variability of the ranks into two or three parts:

- The variability due to the differences among the column effects
- The variability due to the interaction between rows and columns (if `reps` is greater than its default value of 1)
- The remaining variability not explained by any systematic source

The ANOVA table has six columns:

- The first shows the source of the variability.
- The second shows the Sum of Squares (SS) due to each source.
- The third shows the degrees of freedom (df) associated with each source.
- The fourth shows the Mean Squares (MS), which is the ratio SS/df.
- The fifth shows Friedman’s chi-square statistic.
- The sixth shows the p value for the chi-square statistic.

`p = friedman(X, reps, displayopt)` enables the ANOVA table display when `displayopt` is 'on' (default) and suppresses the display when `displayopt` is 'off'.

`[p,table] = friedman(...)` returns the ANOVA table (including column and row labels) in cell array `table`. (You can copy a text version of the ANOVA table to the clipboard by selecting Copy Text from the **Edit** menu.

`[p,table,stats] = friedman(...)` returns a `stats` structure that you can use to perform a follow-up multiple comparison test. The `friedman` test evaluates the hypothesis that the column effects are all the same against the alternative that they are not all the same. Sometimes it is preferable to perform a test to determine which pairs of column effects are significantly different, and which are not. You can use the `multcompare` function to perform such tests by supplying the `stats` structure as input.

Assumptions

Friedman's test makes the following assumptions about the data in `X`:

- All data come from populations having the same continuous distribution, apart from possibly different locations due to column and row effects.
- All observations are mutually independent.

The classical two-way ANOVA replaces the first assumption with the stronger assumption that data come from normal distributions.

Examples

Let's repeat the example from the `anova2` function, this time applying Friedman's test. Recall that the data below come from a study of popcorn brands and popper type (Hogg 1987). The columns of the matrix `popcorn` are brands (Gourmet, National, and Generic). The rows are popper type (Oil and Air). The study popped a batch of each brand three times with each popper. The values are the yield in cups of popped popcorn.

```
load popcorn
popcorn
popcorn =
    5.5000    4.5000    3.5000
    5.5000    4.5000    4.0000
```

friedman

```
6.0000 4.0000 3.0000
6.5000 5.0000 4.0000
7.0000 5.5000 5.0000
7.0000 5.0000 4.5000
```

```
p = friedman(popcorn,3)
p =
0.0010
```

Source	SS	df	MS	Chi-sq	Prob>Chi-sq
Columns	99.75	2	49.875	13.76	0.001
Interaction	0.0833	2	0.0417		
Error	16.1667	12	1.3472		
Total	116	17			

[Test for column effects after row effects are removed](#)

The small p value of 0.001 indicates the popcorn brand affects the yield of popcorn. This is consistent with the results from `anova2`.

References

[1] Hogg, R. V., and J. Ledolter. *Engineering Statistics*. New York: MacMillan, 1987.

[2] Hollander, M., and D. A. Wolfe. *Nonparametric Statistical Methods*. Hoboken, NJ: John Wiley & Sons, Inc., 1999.

See Also

`anova2`

How To

- `multcompare`
- `kruskalwallis`

Purpose

F random numbers

Syntax

```
R = frnd(V1,V2)
R = frnd(V1,V2,m,n,...)
R = frnd(V1,V2,[m,n,...])
```

Description

`R = frnd(V1,V2)` generates random numbers from the F distribution with numerator degrees of freedom $V1$ and denominator degrees of freedom $V2$. $V1$ and $V2$ can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input for $V1$ or $V2$ is expanded to a constant array with the same dimensions as the other input.

`R = frnd(V1,V2,m,n,...)` or `R = frnd(V1,V2,[m,n,...])` generates an m -by- n -by-... array containing random numbers from the F distribution with parameters $V1$ and $V2$. $V1$ and $V2$ can each be scalars or arrays of the same size as R .

Examples

```
n1 = frnd(1:6,1:6)
n1 =
    0.0022    0.3121    3.0528    0.3189    0.2715    0.9539
```

```
n2 = frnd(2,2,[2 3])
n2 =
    0.3186    0.9727    3.0268
    0.2052  148.5816    0.2191
```

```
n3 = frnd([1 2 3;4 5 6],1,2,3)
n3 =
    0.6233    0.2322   31.5458
    2.5848    0.2121    4.4955
```

See Also

[random](#) | [fpdf](#) | [fcdf](#) | [finv](#) | [fstat](#)

How To

- “F Distribution” on page B-38

fstat

Purpose F mean and variance

Syntax `[M,V] = fstat(V1,V2)`

Description `[M,V] = fstat(V1,V2)` returns the mean of and variance for the F distribution with numerator degrees of freedom $V1$ and denominator degrees of freedom $V2$. $V1$ and $V2$ can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of M and V . A scalar input for $V1$ or $V2$ is expanded to a constant arrays with the same dimensions as the other input.

The mean of the F distribution for values of v_2 greater than 2 is

$$\frac{v_2}{v_2 - 2}$$

The variance of the F distribution for values of v_2 greater than 4 is

$$\frac{2v_2^2(v_1 + v_2 - 2)}{v_1(v_2 - 2)^2(v_2 - 4)}$$

The mean of the F distribution is undefined if v_2 is less than 3. The variance is undefined for v_2 less than 5.

Examples `fstat` returns NaN when the mean and variance are undefined.

```
[m,v] = fstat(1:5,1:5)
m =
    NaN    NaN    3.0000    2.0000    1.6667
v =
    NaN    NaN    NaN    NaN    8.8889
```

See Also `fpdf` | `fcdf` | `finv` | `frnd`

How To • “F Distribution” on page B-38

Purpose

Interactive contour plot

Syntax

```
fsurfht(fun,xlims,ylim)  
fsurfht(fun,xlims,ylim,p1,p2,p3,p4,p5)
```

Description

`fsurfht(fun,xlims,ylim)` is an interactive contour plot of the function specified by the text variable `fun`. The x -axis limits are specified by `xlims` in the form `[xmin xmax]`, and the y -axis limits are specified by `ylim` in the form `[ymin ymax]`.

`fsurfht(fun,xlims,ylim,p1,p2,p3,p4,p5)` allows for five optional parameters that you can supply to the function `fun`.

The intersection of the vertical and horizontal reference lines on the plot defines the current x value and y value. You can drag these reference lines and watch the calculated z -values (at the top of the plot) update simultaneously. Alternatively, you can type the x value and y value into editable text fields on the x -axis and y -axis.

Examples

Plot the Gaussian likelihood function for the `gas.mat` data.

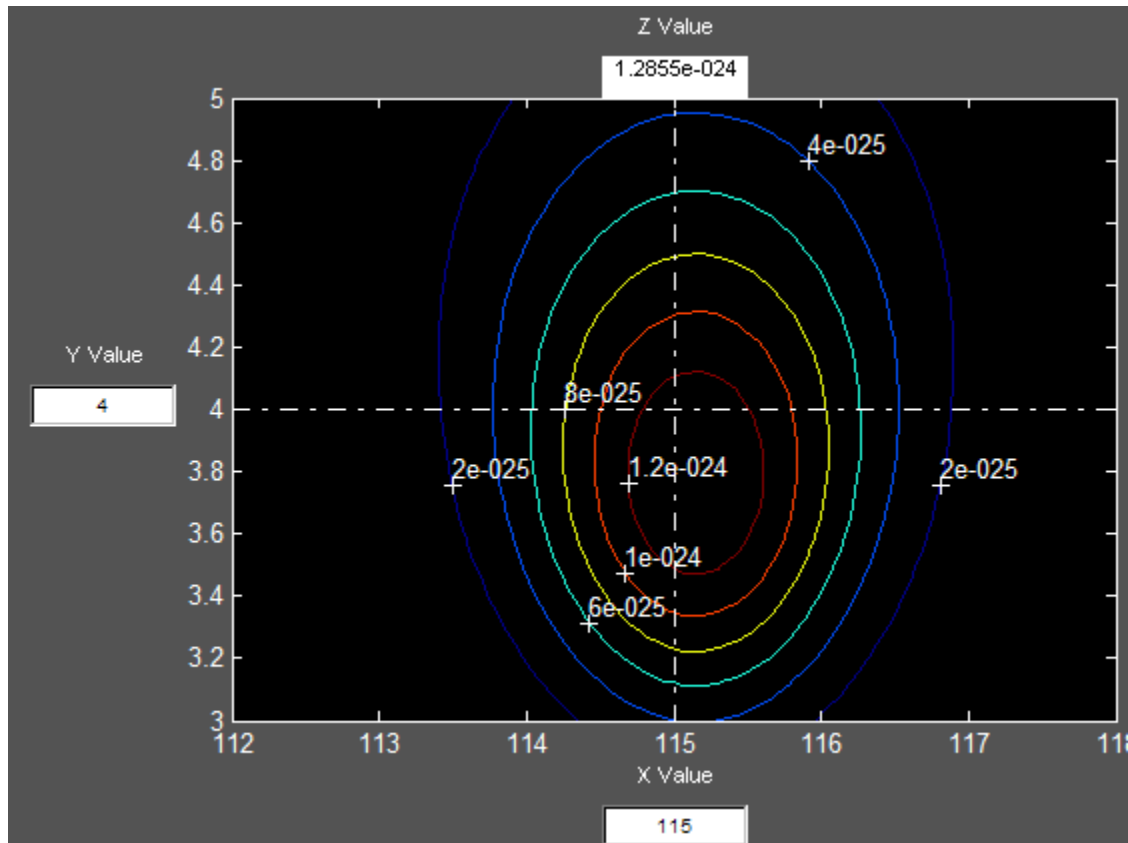
```
load gas
```

Create a function containing the following commands, and name it `gauslike.m`.

```
function z = gauslike(mu,sigma,p1)  
n = length(p1);  
z = ones(size(mu));  
for i = 1:n  
z = z .* (normpdf(p1(i),mu,sigma));  
end
```

The `gauslike` function calls `normpdf`, treating the data sample as fixed and the parameters μ and σ as variables. Assume that the gas prices are normally distributed, and plot the likelihood surface of the sample.

```
fsurfht('gauslike',[112 118],[3 5],price1)
```



The sample mean is the x value at the maximum, but the sample standard deviation is *not* the y value at the maximum.

```
mumax = mean(price1)
mumax =
    115.1500
sigmax = std(price1)*sqrt(19/20)
sigmax =
    3.7719
```


fullfact

Purpose Full factorial design

Syntax `dFF = fullfact(levels)`

Description `dFF = fullfact(levels)` gives factor settings `dFF` for a full factorial design with n factors, where the number of levels for each factor is given by the vector `levels` of length n . `dFF` is m -by- n , where m is the number of treatments in the full-factorial design. Each row of `dFF` corresponds to a single treatment. Each column contains the settings for a single factor, with integer values from one to the number of levels.

Examples The following generates an eight-run full-factorial design with two levels in the first factor and four levels in the second factor:

```
dFF = fullfact([2 4])
dFF =
     1     1
     2     1
     1     2
     2     2
     1     3
     2     3
     1     4
     2     4
```

See Also `ff2n`

Purpose

Gage repeatability and reproducibility study

Syntax

```
gagerr(y, {part, operator})  
gagerr(y, GROUP)  
gagerr(y, part)  
gagerr(..., param1, val1, param2, val2, ...)  
[TABLE, stats] = gagerr(...)
```

Description

`gagerr(y, {part, operator})` performs a gage repeatability and reproducibility study on measurements in `y` collected by `operator` on `part`. `y` is a column vector containing the measurements on different parts. `part` and `operator` are categorical variables, numeric vectors, character matrices, or cell arrays of strings. The number of elements in `part` and `operator` should be the same as in `y`.

`gagerr` prints a table in the command window in which the decomposition of variance, standard deviation, study var (5.15 x standard deviation) are listed with respective percentages for different sources. Summary statistics are printed below the table giving the number of distinct categories (NDC) and the percentage of Gage R&R of total variations (PRR).

`gagerr` also plots a bar graph showing the percentage of different components of variations. Gage R&R, repeatability, reproducibility, and part-to-part variations are plotted as four vertical bars. Variance and study var are plotted as two groups.

To determine the capability of a measurement system using NDC, use the following guidelines:

- If $NDC > 5$, the measurement system is capable.
- If $NDC < 2$, the measurement system is not capable.
- Otherwise, the measurement system may be acceptable.

To determine the capability of a measurement system using PRR, use the following guidelines:

- If $PRR < 10\%$, the measurement system is capable.

- If $PRR > 30\%$, the measurement system is not capable.
- Otherwise, the measurement system may be acceptable.

`gagerr(y, GROUP)` performs a gage R&R study on measurements in `y` with part and operator represented in `GROUP`. `GROUP` is a numeric matrix whose first and second columns specify different parts and operators, respectively. The number of rows in `GROUP` should be the same as the number of elements in `y`.

`gagerr(y, part)` performs a gage R&R study on measurements in `y` without operator information. The assumption is that all variability is contributed by `part`.

`gagerr(..., param1, val1, param2, val2, ...)` performs a gage R&R study using one or more of the following parameter name/value pairs:

- `'spec'` — A two-element vector that defines the lower and upper limit of the process, respectively. In this case, summary statistics printed in the command window include Precision-to-Tolerance Ratio (PTR). Also, the bar graph includes an additional group, the percentage of tolerance.

To determine the capability of a measurement system using PTR, use the following guidelines:

- If $PTR < 0.1$, the measurement system is capable.
- If $PTR > 0.3$, the measurement system is not capable.
- Otherwise, the measurement system may be acceptable.
- `'printtable'` — A string with a value `'on'` or `'off'` that indicates whether the tabular output should be printed in the command window or not. The default value is `'on'`.
- `'printgraph'` — A string with a value `'on'` or `'off'` that indicates whether the bar graph should be plotted or not. The default value is `'on'`.
- `'randomoperator'` — A logical value, `true` or `false`, that indicates whether the effect of operator is random or not. The default value is `true`.

- 'model' — The model to use, specified by one of:
 - 'linear' — Main effects only (default)
 - 'interaction' — Main effects plus two-factor interactions
 - 'nested' — Nest operator in part

The default value is 'linear'.

[TABLE, stats] = gagerr(...) returns a 6-by-5 matrix TABLE and a structure stats. The columns of TABLE, from left to right, represent variance, percentage of variance, standard deviations, study var, and percentage of study var. The rows of TABLE, from top to bottom, represent different sources of variations: gage R&R, repeatability, reproducibility, operator, operator and part interactions, and part. stats is a structure containing summary statistics for the performance of the measurement system. The fields of stats are:

- ndc — Number of distinct categories
- prr — Percentage of gage R&R of total variations
- ptr — Precision-to-tolerance ratio. The value is NaN if the parameter 'spec' is not given.

Examples

Conduct a gage R&R study for a simulated measurement system using a mixed ANOVA model without interactions:

```
y = randn(100,1); % measurements
part = ceil(3*rand(100,1)); % parts
operator = ceil(4*rand(100,1)); % operators
gagerr(y,{part, operator},'randomoperator',true) % analysis
```

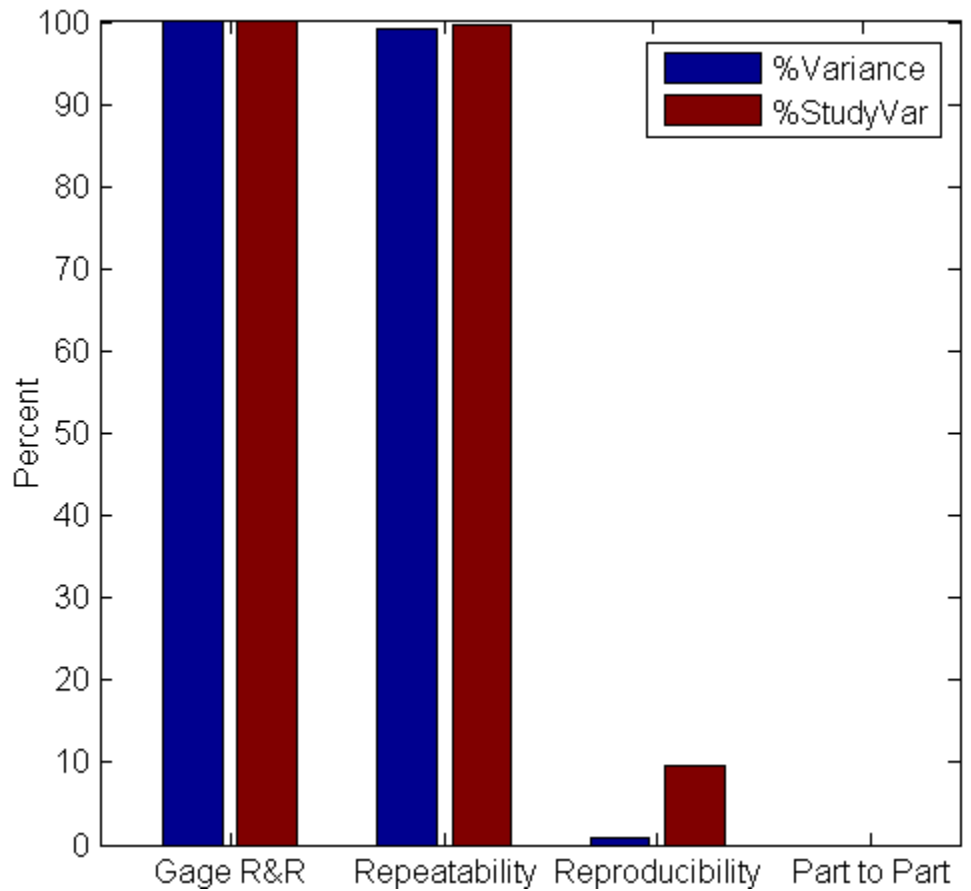
Source	Variance	% Variance	sigma	5.15*sigma	% 5.15*sigma
Gage R&R	0.77	100.00	0.88	4.51	100.00
Repeatability	0.76	99.08	0.87	4.49	99.54
Reproducibility	0.01	0.92	0.08	0.43	9.61
Operator	0.01	0.92	0.08	0.43	9.61
Part	0.00	0.00	0.00	0.00	0.00

Total	0.77	100.00	0.88	4.51
-------	------	--------	------	------

Number of distinct categories (NDC): 0

% of Gage R&R of total variations (PRR): 100.00

Note: The last column of the above table does not have to sum to 100%



How To

- “Grouping Variables” on page 2-72

gamcdf

Purpose Gamma cumulative distribution function

Syntax `gamcdf(X,A,B)`
`[P, PLO, PUP] = gamcdf(X,A,B,pcov,alpha)`

Description `gamcdf(X,A,B)` computes the gamma cdf at each of the values in `X` using the corresponding shape parameters in `A` and scale parameters in `B`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `A` and `B` must be positive.

The gamma cdf is

$$p = F(x | a, b) = \frac{1}{b^a \Gamma(a)} \int_0^x t^{a-1} e^{-\frac{t}{b}} dt$$

The result, p , is the probability that a single observation from a gamma distribution with parameters a and b will fall in the interval $[0, x]$.

`[P, PLO, PUP] = gamcdf(X,A,B,pcov,alpha)` produces confidence bounds for `P` when the input parameters `A` and `B` are estimates. `pcov` is a 2-by-2 matrix containing the covariance matrix of the estimated parameters. `alpha` has a default value of 0.05, and specifies 100(1-alpha)% confidence bounds. `PLO` and `PUP` are arrays of the same size as `P` containing the lower and upper confidence bounds.

`gammainc` is the gamma distribution with b fixed at 1.

Examples

```
a = 1:6;  
b = 5:10;  
prob = gamcdf(a.*b,a,b)  
prob =  
    0.6321    0.5940    0.5768    0.5665    0.5595    0.5543
```


The mean of the gamma distribution is the product of the parameters, ab . In this example, the mean approaches the median as it increases (i.e., the distribution becomes more symmetric).

See Also

[cdf](#) | [gampdf](#) | [gaminv](#) | [gamstat](#) | [gamfit](#) | [gamlike](#) | [gamrnd](#) | [gamma](#)

How To

- “Gamma Distribution” on page B-40

gamfit

Purpose

Gamma parameter estimates

Syntax

```
phat = gamfit(data)
[phat,pci] = gamfit(data)
[phat,pci] = gamfit(data,alpha)
[...] = gamfit(data,alpha,censoring,freq,options)
```

Description

`phat = gamfit(data)` returns the maximum likelihood estimates (MLEs) for the parameters of the gamma distribution given the data in vector `data`.

`[phat,pci] = gamfit(data)` returns MLEs and 95% percent confidence intervals. The first row of `pci` is the lower bound of the confidence intervals; the last row is the upper bound.

`[phat,pci] = gamfit(data,alpha)` returns $100(1 - \alpha)\%$ confidence intervals. For example, `alpha = 0.01` yields 99% confidence intervals.

`[...] = gamfit(data,alpha,censoring)` accepts a Boolean vector of the same size as `data` that is 1 for observations that are right-censored and 0 for observations that are observed exactly.

`[...] = gamfit(data,alpha,censoring,freq)` accepts a frequency vector of the same size as `data`. `freq` typically contains integer frequencies for the corresponding elements in `data`, but may contain any nonnegative values.

`[...] = gamfit(data,alpha,censoring,freq,options)` accepts a structure, `options`, that specifies control parameters for the iterative algorithm the function uses to compute maximum likelihood estimates. The gamma fit function accepts an `options` structure which can be created using the function `statset`. Enter `statset('gamfit')` to see the names and default values of the parameters that `gamfit` accepts in the `options` structure.

Examples

Fit a gamma distribution to random data generated from a specified gamma distribution:

```
a = 2; b = 4;
data = gamrnd(a,b,100,1);

[p,ci] = gamfit(data)
p =
    2.1990    3.7426
ci =
    1.6840    2.8298
    2.7141    4.6554
```

References

[1] Hahn, Gerald J., and S. S. Shapiro. *Statistical Models in Engineering*. Hoboken, NJ: John Wiley & Sons, Inc., 1994, p. 88.

See Also

mle | gamlike | gampdf | gamcdf | gaminv | gamstat | gamrnd

How To

- “Gamma Distribution” on page B-40

gaminv

Purpose Gamma inverse cumulative distribution function

Syntax
`X = gaminv(P,A,B)`
`[X,XLO,XUP] = gamcdf(P,A,B,pcov,alpha)`

Description `X = gaminv(P,A,B)` computes the inverse of the gamma cdf with shape parameters in `A` and scale parameters in `B` for the corresponding probabilities in `P`. `P`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `A` and `B` must all be positive, and the values in `P` must lie on the interval `[0 1]`.

The gamma inverse function in terms of the gamma cdf is

$$x = F^{-1}(p | a, b) = \{x : F(x | a, b) = p\}$$

where

$$p = F(x | a, b) = \frac{1}{b^a \Gamma(a)} \int_0^x t^{a-1} e^{-\frac{t}{b}} dt$$

`[X,XLO,XUP] = gamcdf(P,A,B,pcov,alpha)` produces confidence bounds for `P` when the input parameters `A` and `B` are estimates. `pcov` is a 2-by-2 matrix containing the covariance matrix of the estimated parameters. `alpha` has a default value of 0.05, and specifies 100(1-alpha)% confidence bounds. `PLO` and `PUP` are arrays of the same size as `P` containing the lower and upper confidence bounds.

Algorithms There is no known analytical solution to the integral equation above. `gaminv` uses an iterative approach (Newton's method) to converge on the solution.

Examples This example shows the relationship between the gamma cdf and its inverse function.

```
a = 1:5;  
b = 6:10;  
x = gaminv(gamcdf(1:5,a,b),a,b)  
x =  
  1.0000  2.0000  3.0000  4.0000  5.0000
```

See Also

[icdf](#) | [gamcdf](#) | [gampdf](#) | [gamstat](#) | [gamfit](#) | [gamlike](#) | [gamrnd](#)

How To

- “Gamma Distribution” on page B-40

gamlike

Purpose

Gamma negative log-likelihood

Syntax

```
nlogL = gamlike(params,data)
[nlogL,AVAR] = gamlike(params,data)
```

Description

`nlogL = gamlike(params,data)` returns the negative of the gamma log-likelihood of the parameters, `params`, given `data`. `params(1)=A`, shape parameters, and `params(2)=B`, scale parameters.

`[nlogL,AVAR] = gamlike(params,data)` also returns `AVAR`, which is the asymptotic variance-covariance matrix of the parameter estimates when the values in `params` are the maximum likelihood estimates. `AVAR` is the inverse of Fisher's information matrix. The diagonal elements of `AVAR` are the asymptotic variances of their respective parameters.

`[...] = gamlike(params,data,censoring)` accepts a Boolean vector of the same size as `data` that is 1 for observations that are right-censored and 0 for observations that are observed exactly.

`[...] = gamfit(params,data,censoring,freq)` accepts a frequency vector of the same size as `data`. `freq` typically contains integer frequencies for the corresponding elements in `data`, but may contain any non-negative values.

`gamlike` is a utility function for maximum likelihood estimation of the gamma distribution. Since `gamlike` returns the negative gamma log-likelihood function, minimizing `gamlike` using `fminsearch` is the same as maximizing the likelihood.

Examples

Compute the negative log-likelihood of parameter estimates computed by the `gamfit` function:

```
a = 2; b = 3;
r = gamrnd(a,b,100,1);

[nlogL,AVAR] = gamlike(gamfit(r),r)
nlogL =
    267.5648
AVAR =
```

0.0788 -0.1104
-0.1104 0.1955

See Also

[gamfit](#) | [gampdf](#) | [gamcdf](#) | [gaminv](#) | [gamstat](#) | [gamrnd](#)

How To

- “Gamma Distribution” on page B-40

gampdf

Purpose Gamma probability density function

Syntax `Y = gampdf(X,A,B)`

Description `Y = gampdf(X,A,B)` computes the gamma pdf at each of the values in `X` using the corresponding shape parameters in `A` and scale parameters in `B`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `A` and `B` must all be positive, and the values in `X` must lie on the interval $[0 \infty)$.

The gamma pdf is

$$y = f(x | a, b) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}}$$

The gamma probability density function is useful in reliability models of lifetimes. The gamma distribution is more flexible than the exponential distribution in that the probability of a product surviving an additional period may depend on its current age. The exponential and χ^2 functions are special cases of the gamma function.

Examples The exponential distribution is a special case of the gamma distribution.

```
mu = 1:5;
```

```
y = gampdf(1,1,mu)
```

```
y =  
0.3679 0.3033 0.2388 0.1947 0.1637
```

```
y1 = exppdf(1,mu)
```

```
y1 =  
0.3679 0.3033 0.2388 0.1947 0.1637
```

See Also `pdf` | `gamcdf` | `gaminv` | `gamstat` | `gamfit` | `gamlike` | `gamrnd`

How To

- “Gamma Distribution” on page B-40

gamrnd

Purpose Gamma random numbers

Syntax
R = gamrnd(A,B)
R = gamrnd(A,B,m,n,...)
R = gamrnd(A,B,[m,n,...])

Description R = gamrnd(A,B) generates random numbers from the gamma distribution with shape parameters in A and scale parameters in B. A and B can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input for A or B is expanded to a constant array with the same dimensions as the other input.

R = gamrnd(A,B,m,n,...) or R = gamrnd(A,B,[m,n,...]) generates an m-by-n-by-... array containing random numbers from the gamma distribution with parameters A and B. A and B can each be scalars or arrays of the same size as R.

Examples

```
n1 = gamrnd(1:5,6:10)
n1 =
    9.1132    12.8431    24.8025    38.5960   106.4164

n2 = gamrnd(5,10,[1 5])
n2 =
    30.9486    33.5667    33.6837    55.2014    46.8265

n3 = gamrnd(2:6,3,1,5)
n3 =
    12.8715    11.3068     3.0982    15.6012    21.6739
```

See Also randg | random | gampdf | gamcdf | gaminv | gamstat | gamfit | gamlike

How To • “Gamma Distribution” on page B-40

Purpose Gamma mean and variance

Syntax `[M,V] = gamstat(A,B)`

Description `[M,V] = gamstat(A,B)` returns the mean of and variance for the gamma distribution with shape parameters in *A* and scale parameters in *B*. *A* and *B* can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of *M* and *V*. A scalar input for *A* or *B* is expanded to a constant array with the same dimensions as the other input.

The mean of the gamma distribution with parameters *a* and *b* is ab . The variance is ab^2 .

Examples `[m,v] = gamstat(1:5,1:5)`

```
m =  
    1    4    9   16   25  
v =  
    1    8   27   64  125
```

```
[m,v] = gamstat(1:5,1./(1:5))
```

```
m =  
    1    1    1    1    1  
v =  
  1.0000  0.5000  0.3333  0.2500  0.2000
```

See Also `gampdf` | `gamcdf` | `gaminv` | `gamfit` | `gamlike` | `gamrnd`

How To • “Gamma Distribution” on page B-40

Purpose Greater than or equal relation for handles

Syntax `h1 >= h2`

Description `h1 >= h2` performs element-wise comparisons between handle arrays `h1` and `h2`. `h1` and `h2` must be of the same dimensions unless one is a scalar. The result is a logical array of the same dimensions, where each element is an element-wise `>=` result.

If one of `h1` or `h2` is scalar, scalar expansion is performed and the result will match the dimensions of the array that is not scalar.

`tf = ge(h1, h2)` stores the result in a logical array of the same dimensions.

See Also `grandstream` | `eq` | `gt` | `le` | `lt` | `ne`

Purpose	Generalized linear regression model class
Description	An object comprising training data, model description, diagnostic information, and fitted coefficients for a generalized linear regression. Predict model responses with the <code>predict</code> or <code>feval</code> methods.
Construction	<p><code>mdl = GeneralizedLinearModel.fit(ds)</code> or <code>mdl = GeneralizedLinearModel.fit(X,y)</code> creates a generalized linear model of a dataset array <code>ds</code>, or of the responses <code>y</code> to a data matrix <code>X</code>. For details, see <code>GeneralizedLinearModel.fit</code>.</p> <p><code>mdl = GeneralizedLinearModel.stepwise(ds)</code> or <code>mdl = GeneralizedLinearModel.stepwise(X,y)</code> creates a generalized linear model of a dataset array <code>ds</code>, or of the responses <code>y</code> to a data matrix <code>X</code>, with unimportant predictors excluded. For details, see <code>GeneralizedLinearModel.stepwise</code>.</p>

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors can be numeric, or can be any grouping variable type, such as logical or categorical (see “Grouping Variables” on page 2-72). The response must be numeric or logical.

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

X

Matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as `X`. Each entry in `y` is the response to the data in the corresponding row of `X`.

GeneralizedLinearModel

Properties

CoefficientCovariance

Covariance matrix of coefficient estimates.

CoefficientNames

Cell array of strings containing a label for each coefficient.

Coefficients

Table of coefficient values in a dataset array. `Coefficients` has one row for each coefficient and these columns:

- `Estimate` — Estimated coefficient value
- `SE` — Standard error of the estimate
- `tStat` — t statistic for a test that the coefficient is zero
- `pValue` — p -value for the t statistic

To obtain any of these columns as a vector, index into the property using dot notation. For example, in `mdl` the estimated coefficient vector is

```
beta = mdl.Coefficients.Estimate
```

Use `coefTest` to perform other tests on the coefficients.

Deviance

Deviance of the fit, equal to $-2 * \text{LogLikelihood}$.

Deviance is useful for comparing two models when one is a special case of the other. The difference D between the deviance of the two models is -2 times the log of the likelihood ratio. Asymptotically, D has a chi-square distribution with degrees of freedom V equal to the number of parameters that are estimated in one model but fixed (typically at 0) in the other. The p -value for this test is $1 - \text{chi2cdf}(D, V)$.

DFE

Degrees of freedom for error (residuals), equal to the number of observations minus the number of estimated coefficients.

Diagnostics

Dataset array with diagnostics helpful in finding outliers and influential observations. The structure contains the following fields:

Field	Meaning	Utility
Leverage	Diagonal elements of HatMatrix	Leverage indicates to what extent the predicted value for an observation is determined by the observed value for that observation. A value close to 1 indicates that the prediction is largely determined by that observation, with little contribution from the other observations. A value close to 0 indicates the fit is largely determined by the other observations. For a model with P coefficients and N observations, the average value of Leverage is P/N. An observation with Leverage larger than $2 \cdot P/N$ can be an outlier.
CooksDistance	Cook's measure of scaled change in fitted values	CooksDistance is a measure of scaled change in fitted values. An observation with CooksDistance larger than three times the mean Cook's distance can be an outlier.
HatMatrix	Projection matrix to compute fitted from observed responses	HatMatrix is an N-by-N matrix such that $\text{Fitted} = \text{HatMatrix} \cdot Y$, where Y is the response vector and Fitted is the vector of fitted response values.

All of these quantities are computed on the scale of the linear predictor. So, for example, in the equation that defines the hat matrix,

$$Y_{\text{fit}} = \text{glm.Fitted.LinearPredictor}$$
$$Y = \text{glm.Fitted.LinearPredictor} + \text{glm.Residuals.LinearPredictor}$$

GeneralizedLinearModel

Dispersion

Scale factor of the variance of the response. Dispersion multiplies the variance function for the distribution.

For example, the variance function for the binomial distribution is $p(1-p)/n$, where p is the probability parameter and n is the sample size parameter. If Dispersion is near 1, the variance of the data appears to agree with the theoretical variance of the binomial distribution. If Dispersion is larger than 1, the data are “overdispersed” relative to the binomial distribution.

DispersionEstimated

Logical value indicating whether `GeneralizedLinearModel.fit` used the Dispersion property to compute standard errors for the coefficients in `Coefficients.SE`. If DispersionEstimated is false, `GeneralizedLinearModel.fit` used the theoretical value of the variance.

- DispersionEstimated can be false only for 'binomial' or 'poisson' distributions.
- Set DispersionEstimated by setting the DispersionFlag name-value pair in `GeneralizedLinearModel.fit`.

Distribution

Structure with the following fields relating to the generalized distribution:

Field	Description
Name	Name of the distribution, one of 'normal', 'binomial', 'poisson', 'gamma', or 'inverse gamma'.
DevianceFunction	Function that computes the components of the deviance as a function of the fitted parameter values and the response values.
VarianceFunction	Function that computes the theoretical variance for the distribution as a function of the fitted parameter values. When DispersionEstimated is true, Dispersion multiplies the variance function in the computation of the coefficient standard errors.

Fitted

Table of predicted (fitted) values based on the training data, a dataset array with one row for each observation and the following columns.

Field	Description
Response	Predicted values on the scale of the response.
LinearPredictor	Predicted values on the scale of the linear predictor. These are the same as the link function applied to the Response fitted values.
Probability	Fitted probabilities (this column is included only with the binomial distribution).

To obtain any of the columns as a vector, index into the property using dot notation. For example, in the model `mdl`, the vector `f` of fitted values on the response scale is

```
f = mdl.Fitted.Response
```

Use `predict` to compute predictions for other predictor values, or to compute confidence bounds on `Fitted`.

Formula

Object containing information about the model.

GeneralizedLinearModel

Link

Structure with fields relating to the link function. The link is a function f that links the distribution parameter μ to the fitted linear combination Xb of the predictors:

$$f(\mu) = Xb.$$

The structure has the following fields.

Field	Description
Name	Name of the link function, or '' if you specified the link as a function handle rather than a string.
LinkFunction	The function that defines f , a function handle.
DevianceFunction	Derivative of f , a function handle.
VarianceFunction	Inverse of f , a function handle.

LogLikelihood

Log likelihood of the model distribution at the response values, with mean fitted from the model, and other parameters estimated as part of the model fit.

ModelCriterion

AIC and other information criteria for comparing models. A structure with fields:

- AIC — Akaike information criterion
- AICc — Akaike information criterion corrected for sample size
- BIC — Bayesian information criterion
- CAIC — Consistent Akaike information criterion

To obtain any of these values as a scalar, index into the property using dot notation. For example, in a model `mdl`, the AIC value `aic` is:

```
aic = mdl.ModelCriterion.AIC
```

NumCoefficients

Number of coefficients in the model, a positive integer. `NumCoefficients` includes coefficients that are set to zero when the model terms are rank deficient.

NumEstimatedCoefficients

Number of estimated coefficients in the model, a positive integer. `NumEstimatedCoefficients` does not include coefficients that are set to zero when the model terms are rank deficient. `NumEstimatedCoefficients` is the degrees of freedom for regression.

NumObservations

Number of observations the fitting function used in fitting. This is the number of observations supplied in the original dataset or matrix, minus any excluded rows (set with the `Excluded` name-value pair) or rows with missing values.

NumPredictors

Number of variables `LinearModel.fit` used as predictors for fitting.

NumVariables

Number of variables in the data. `NumVariables` is the number of variables in the original dataset when the fit is based on a dataset, or the total number of columns in the predictor matrix and response vector when the fit is based on those arrays. It includes variables, if any, that are not used as predictors or as the response.

ObservationInfo

Dataset with the same number of rows as the input data (`ds` or `X`).

GeneralizedLinearModel

Field	Description
Weights	Observation weights. Default is all 1.
Excluded	Logical value, 1 indicates an observation that you excluded from the fit with the Exclude name-value pair.
Missing	Logical value, 1 indicates a missing value in the input. Missing values are not used in the fit.
Subset	Logical value, 1 indicates the observation is not excluded or missing, so is used in the fit.

ObservationNames

Cell array of strings containing the names of the observations used in the fit.

- If the fit is based on a dataset containing observation names, `ObservationNames` uses those names.
- Otherwise, `ObservationNames` is an empty cell array

Offset

Vector with the same length as the number of rows in the data, passed from `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise` in the `Offset` name-value pair. The fitting function used `Offset` as a predictor variable, but with the coefficient set to exactly 1. In other words, the formula for fitting was

$$\mu \sim \text{Offset} + (\text{terms involving real predictors})$$

with the `Offset` predictor having coefficient 1.

For example, consider a Poisson regression model. Suppose the number of counts is known for theoretical reasons to be proportional to a predictor A. By using the log link function and by

specifying $\log(A)$ as an offset, you can force the model to satisfy this theoretical constraint.

PredictorNames

Cell array of strings, the names of the predictors used in fitting the model.

Residuals

Dataset array containing a table of residuals, with one row for each observation and these variables.

Field	Description
Raw	Observed minus fitted values.
LinearPredictor	Residuals on the linear predictor scale, equal to the adjusted response value minus the fitted linear combination of the predictors.
Pearson	Raw residuals divided by the estimated standard deviation of the response.
Anscombe	Residuals defined on transformed data with the transformation chosen to remove skewness.
Deviance	Residuals based on the contribution of each observation to the deviance.

To obtain any of these columns as a vector, index into the property using dot notation. For example, in a model `mdl`, the ordinary raw residual vector `r` is:

```
r = mdl.Residuals.Raw
```

Rows not used in the fit because of missing values (in `ObservationInfo.Missing`) contain NaN values.

Rows not used in the fit because of excluded values (in `ObservationInfo.Excluded`) contain NaN values, with the following exceptions:

GeneralizedLinearModel

- `raw` contains the difference between the observed and predicted values.
- `standardized` is the residual, standardized in the usual way.
- `studentized` matches the standardized values because this residual is not used in the estimate of the residual standard deviation.

ResponseName

String giving naming the response variable.

Rsquared

Proportion of total sum of squares explained by the model. The ordinary R-squared value relates to the SSR and SST properties:

$$\text{Rsquared} = \text{SSR}/\text{SST} = 1 - \text{SSE}/\text{SST}.$$

Rsquared is a structure with two fields:

- `Ordinary` — Ordinary (unadjusted) R-squared
- `Adjusted` — R-squared adjusted for the number of coefficients

To obtain any of these values as a scalar, index into the property using dot notation. For example, the adjusted R-squared value in `mdl` is

```
r2 = mdl.Rsquared.Adjusted
```

SSE

Sum of squared errors (residuals).

The Pythagorean theorem implies

$$\text{SST} = \text{SSE} + \text{SSR}.$$

SSR

Regression sum of squares, the sum of squared deviations of the fitted values from their mean.

The Pythagorean theorem implies

$$\text{SST} = \text{SSE} + \text{SSR}.$$

SST

Total sum of squares, the sum of squared deviations of y from $\text{mean}(y)$.

The Pythagorean theorem implies

$$\text{SST} = \text{SSE} + \text{SSR}.$$

Steps

Structure that is empty unless `LinearModel.stepwise` constructed the model.

Field	Description
Start	Formula representing the starting model
Lower	Formula representing the lower bound model, these terms that must remain in the model
Upper	Formula representing the upper bound model, model cannot contain more terms than Upper
Criterion	Criterion used for the stepwise algorithm, such as 'sse'
PEnter	Value of the parameter, such as 0.05
PRemove	Value of the parameter, such as 0.10
History	Dataset representing the steps taken in the fit

The `History` dataset has one row for each step including the initial fit, and the following variables (columns).

GeneralizedLinearModel

Field	Description
Action	Action taken during this step, one of: <ul style="list-style-type: none">• 'Start' — First step• 'Add' — A term is added• 'Remove' — A term is removed
TermName	<ul style="list-style-type: none">• 'Start' step: The starting model specification• 'Add' or 'Remove' steps: The term moved in that step
Terms	Terms matrix (see <code>modelspec</code> in “Input Arguments” on page 20-709 of <code>LinearModel.fit</code>)
DF	Regression degrees of freedom after this step
delDF	Change in regression degrees of freedom from previous step (negative for steps that remove a term)
Deviance	Deviance (residual sum of squares) at that step
FStat	F statistic that led to this step
PValue	p -value of the F statistic

VariableInfo

Dataset array containing metadata about `Variables`. There is one row for each term in the model, and the following columns.

Field	Description
Class	String giving variable class, such as 'double'
Range	Cell array giving variable range: <ul style="list-style-type: none">• Continuous variable — Two-element vector $[min, max]$, the minimum and maximum values• Categorical variable — Cell array of distinct variable values
InModel	Logical vector, where true indicates the variable is in the model
IsCategorical	Logical vector, where true indicates a categorical variable

VariableNames

Cell array of strings containing names of the variables in the fit.

- If the fit is based on a dataset, this property provides the names of the variables in that dataset.
- If the fit is based on a predictor matrix and response vector, `VariableNames` is the values in the `VarNames` name-value pair of the fitting method.
- Otherwise the variables have the default fitting names.

Variables

Dataset array containing the data, both observations and responses, that the fitting function used to construct the fit. If the fit is based on a dataset array, `Variables` is a copy of that dataset. Otherwise, `Variables` is a dataset created from the input data matrix X and response vector y .

GeneralizedLinearModel

Methods

<code>addTerms</code>	Add terms to generalized linear model
<code>coefCI</code>	Confidence intervals of coefficient estimates of generalized linear model
<code>coefTest</code>	Linear hypothesis test on generalized linear regression model coefficients
<code>devianceTest</code>	Analysis of deviance
<code>disp</code>	Display generalized linear regression model
<code>feval</code>	Evaluate generalized linear regression model prediction
<code>fit</code>	Create generalized linear regression model
<code>plotDiagnostics</code>	Plot diagnostics of generalized linear regression model
<code>plotResiduals</code>	Plot residuals of generalized linear regression model
<code>plotSlice</code>	Plot of slices through fitted generalized linear regression surface
<code>predict</code>	Predict response of generalized linear regression model
<code>random</code>	Simulate responses for generalized linear regression model
<code>removeTerms</code>	Remove terms from generalized linear model

step	Improve generalized linear regression model by adding or removing terms
stepwise	Create generalized linear regression model by stepwise regression

Definitions Canonical Link Function

The default link function for a generalized linear model is the *canonical link function*.

Canonical Link Functions for Generalized Linear Models

Distribution	Link Function Name	Link Function	Mean (Inverse) Function
'normal'	'identity'	$f(\mu) = \mu$	$\mu = Xb$
'binomial'	'logit'	$f(\mu) = \log(\mu/(1-\mu))$	$\mu = \exp(Xb) / (1 + \exp(Xb))$
'poisson'	'log'	$f(\mu) = \log(\mu)$	$\mu = \exp(Xb)$
'gamma'	-1	$f(\mu) = 1/\mu$	$\mu = 1/(Xb)$
'inverse gaussian'	-2	$f(\mu) = 1/\mu^2$	$\mu = (Xb)^{-1/2}$

Hat Matrix

The *hat matrix* H is defined in terms of the data matrix X and a diagonal weight matrix W :

$$H = X(X^T W X)^{-1} X^T W^T.$$

W has diagonal elements w_i :

Generalized Linear Model

$$w_i = \frac{g'(\mu_i)}{\sqrt{V(\mu_i)}},$$

where

- g is the link function mapping y_i to $x_i b$.
- g' is the derivative of the link function g .
- V is the variance function.
- μ_i is the i th mean.

The diagonal elements H_{ii} satisfy

$$0 \leq h_{ii} \leq 1$$
$$\sum_{i=1}^n h_{ii} = p,$$

where n is the number of observations (rows of X), and p is the number of coefficients in the regression model.

Leverage

The *leverage* of observation i is the value of the i th diagonal term of the hat matrix H_{ii} . Because the sum of the leverage values is p (the number of coefficients in the regression model), an observation i can be considered to be an outlier if its leverage substantially exceeds p/n , where n is the number of observations.

Cook's Distance

The Cook's distance D_i of observation i is

$$D_i = w_i \frac{e_i^2}{p\hat{\sigma}^2} \frac{h_{ii}}{(1-h_{ii})^2},$$

where

- $\hat{\phi}$ is the dispersion parameter (estimated or theoretical).
- e_i is the linear predictor residual, $g(y_i) - x_i\hat{\beta}$, where
 - g is the link function.
 - y_i is the observed response.
 - x_i is the observation.
 - $\hat{\beta}$ is the estimated coefficient vector.
- p is the number of coefficients in the regression model.
- h_{ii} is the i th diagonal element of the Hat Matrix H .

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Fit a Generalized Linear Model

Make a logistic binomial model of the probability of smoking as a function of age, weight, and sex, using a two-way interactions model.

Load the hospital dataset array.

```
load hospital
ds = hospital; % just to use the ds name
```

Specify the model using a formula that allows up to two-way interactions.

```
modelspec = 'Smoker ~ Age*Weight*Sex - Age:Weight:Sex';
```

Create the generalized linear model.

```
mdl = GeneralizedLinearModel.fit(ds,...
    modelspec,'Distribution','binomial')
```

```
mdl =
```

GeneralizedLinearModel

```
Generalized Linear regression model:  
logit(Smoker) ~ 1 + Sex*Age + Sex*Weight + Age*Weight  
Distribution = Binomial
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	-6.0492	19.749	-0.3063	0.75938
Sex_Male	-2.2859	12.424	-0.18399	0.85402
Age	0.11691	0.50977	0.22934	0.81861
Weight	0.031109	0.15208	0.20455	0.83792
Sex_Male:Age	0.020734	0.20681	0.10025	0.92014
Sex_Male:Weight	0.01216	0.053168	0.22871	0.8191
Age:Weight	-0.00071959	0.0038964	-0.18468	0.85348

```
100 observations, 93 error degrees of freedom  
Dispersion: 1  
Chi^2-statistic vs. constant model: 5.07, p-value = 0.535
```

The large p -value indicates the model might not differ statistically from a constant.

Create a Generalized Linear Model Stepwise

Create response data using just three of 20 predictors, and create a generalized linear model stepwise to see if it uses just the correct predictors.

Create data with 20 predictors, and Poisson response using just three of the predictors, plus a constant.

```
rng('default') % for reproducibility  
X = randn(100,20);  
mu = exp(X(:,[5 10 15])*[.4;.2;.3] + 1);  
y = poissrnd(mu);
```

Fit a generalized linear model using the Poisson distribution.

```
mdl = GeneralizedLinearModel.stepwise(X,y,...  
    'constant','upper','linear','Distribution','poisson')
```

1. Adding x5, Deviance = 134.439, Chi2Stat = 52.24814, PValue = 4.891229e-13
2. Adding x15, Deviance = 106.285, Chi2Stat = 28.15393, PValue = 1.1204e-07
3. Adding x10, Deviance = 95.0207, Chi2Stat = 11.2644, PValue = 0.000790094

```
mdl =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x5 + x10 + x15  
Distribution = Poisson
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	1.0115	0.064275	15.737	8.4217e-56
x5	0.39508	0.066665	5.9263	3.0977e-09
x10	0.18863	0.05534	3.4085	0.0006532
x15	0.29295	0.053269	5.4995	3.8089e-08

100 observations, 96 error degrees of freedom

Dispersion: 1

Chi^2-statistic vs. constant model: 91.7, p-value = 9.61e-20

See Also

[GeneralizedLinearModel.fit](#) | [GeneralizedLinearModel.stepwise](#)
| [LinearModel](#) | [NonLinearModel](#) |

Related Examples

- “Generalized Linear Model Workflow” on page 9-171

Concepts

- “Generalized Linear Models” on page 9-141

geocdf

Purpose Geometric cumulative distribution function

Syntax `Y = geocdf(X,P)`

Description `Y = geocdf(X,P)` computes the geometric cdf at each of the values in `X` using the corresponding probabilities in `P`. `X` and `P` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input. The parameters in `P` must lie on the interval `[0 1]`.

The geometric cdf is

$$y = F(x | p) = \sum_{i=0}^{\text{floor}(x)} pq^i$$

where $q = 1 - p$.

The result, y , is the probability of observing up to x trials before a success, when the probability of success in any given trial is p .

Examples Suppose you toss a fair coin repeatedly. If the coin lands face up (heads), that is a success. What is the probability of observing three or fewer tails before getting a heads?

```
p = geocdf(3,0.5)
```

```
p =  
0.9375
```

See Also `cdf` | `geopdf` | `geoinv` | `geostat` | `geornd` | `mle`

How To • “Geometric Distribution” on page B-54

Purpose	Geometric inverse cumulative distribution function
Syntax	<code>X = geoinv(Y,P)</code>
Description	<p><code>X = geoinv(Y,P)</code> returns the smallest positive integer <code>X</code> such that the geometric cdf evaluated at <code>X</code> is equal to or exceeds <code>Y</code>. You can think of <code>Y</code> as the probability of observing <code>X</code> successes in a row in independent trials where <code>P</code> is the probability of success in each trial.</p> <p><code>Y</code> and <code>P</code> can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input for <code>P</code> or <code>Y</code> is expanded to a constant array with the same dimensions as the other input. The values in <code>P</code> and <code>Y</code> must lie on the interval <code>[0 1]</code>.</p>
Examples	<p>The probability of correctly guessing the result of 10 coin tosses in a row is less than 0.001 (unless the coin is not fair).</p> <pre>psychic = geoinv(0.999,0.5) psychic = 9</pre> <p>The example below shows the inverse method for generating random numbers from the geometric distribution.</p> <pre>rndgeo = geoinv(rand(2,5),0.5) rndgeo = 0 1 3 1 0 0 1 0 2 0</pre>
See Also	<code>icdf</code> <code>geocdf</code> <code>geopdf</code> <code>geostat</code> <code>geornd</code>
How To	<ul style="list-style-type: none">• “Geometric Distribution” on page B-54

geomean

Purpose Geometric mean

Syntax `m = geomean(x)`
`geomean(X,dim)`

Description `m = geomean(x)` calculates the geometric mean of a sample. For vectors, `geomean(x)` is the geometric mean of the elements in `x`. For matrices, `geomean(X)` is a row vector containing the geometric means of each column. For N-dimensional arrays, `geomean` operates along the first nonsingleton dimension of `X`.

`geomean(X,dim)` takes the geometric mean along the dimension `dim` of `X`.

The geometric mean is

$$m = \left[\prod_{i=1}^n x_i \right]^{\frac{1}{n}}$$

Examples The arithmetic mean is greater than or equal to the geometric mean.

```
x = exprnd(1,10,6);
```

```
geometric = geomean(x)
```

```
geometric =  
    0.7466    0.6061    0.6038    0.2569    0.7539    0.3478
```

```
average = mean(x)
```

```
average =  
    1.3509    1.1583    0.9741    0.5319    1.0088    0.8122
```

See Also `mean` | `median` | `harmmean` | `trimmean`

How To • “Geometric Distribution” on page B-54

Purpose Geometric probability density function

Syntax `Y = geopdf(X,P)`

Description `Y = geopdf(X,P)` computes the geometric pdf at each of the values in `X` using the corresponding probabilities in `P`. `X` and `P` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input. The parameters in `P` must lie on the interval `[0 1]`.

The geometric pdf is

$$y = f(x | p) = pq^x I_{(0,1,\dots)}(x)$$

where $q = 1 - p$.

Examples Suppose you toss a fair coin repeatedly. If the coin lands face up (heads), that is a success. What is the probability of observing exactly three tails before getting a heads?

```
p = geopdf(3,0.5)
```

```
p =  
0.0625
```

See Also `pdf` | `geocdf` | `geoinv` | `geostat` | `geornd`

How To • “Geometric Distribution” on page B-54

geornd

Purpose Geometric random numbers

Syntax
R = geornd(P)
R = geornd(P,m,n,...)
R = geornd(P,[m,n,...])

Description R = geornd(P) generates geometric random numbers with probability parameter P. P can be a vector, a matrix, or a multidimensional array. The size of R is the size of P. The geometric distribution is useful when you want to model the number of successive failures preceding a success, where the probability of success in any given trial is the constant P. The parameters in P must lie in the interval [0 1].

R = geornd(P,m,n,...) or R = geornd(P,[m,n,...]) generates an m-by-n-by-... array containing random numbers from the geometric distribution with probability parameter P. P can be a scalar or an array of the same size as R.

Examples
r1 = geornd(1 ./ 2.^(1:6))
r1 =
2 10 2 5 2 60

r2 = geornd(0.01,[1 5])
r2 =
65 18 334 291 63

r3 = geornd(0.5,1,6)
r3 =
0 7 1 3 1 0

See Also random | geopdf | geocdf | geoinv | geostat

How To • “Geometric Distribution” on page B-54

Purpose Geometric mean and variance

Syntax `[M,V] = geostat(P)`

Description `[M,V] = geostat(P)` returns the mean of and variance for the geometric distribution with corresponding probabilities in P.

The mean of the geometric distribution with parameter p is q/p , where $q = 1-p$. The variance is q/p^2 .

Examples `[m,v] = geostat(1./(1:6))`

```
m =  
    0  1.0000  2.0000  3.0000  4.0000  5.0000  
v =  
    0  2.0000  6.0000 12.0000 20.0000 30.0000
```

See Also `geopdf` | `geocdf` | `geoinv` | `geornd`

How To • “Geometric Distribution” on page B-54

dataset.get

Purpose Access dataset array properties

Syntax

```
get(A)
s = get(A)
p = get(A,PropertyName)
p = get(A,{PropertyName1,PropertyName2,...})
```

Description

`get(A)` displays a list of property/value pairs for the dataset array `A`.

`s = get(A)` returns the values in a scalar structure `s` with field names given by the properties.

`p = get(A,PropertyName)` returns the value of the property specified by the string `PropertyName`.

`p = get(A,{PropertyName1,PropertyName2,...})` allows multiple property names to be specified and returns their values in a cell array.

Examples Create a dataset array from Fisher's iris data and access the information:

```
load fisheriris
NumObs = size(meas,1);
NameObs = strcat({'Obs'},num2str((1:NumObs)','%-d'));
iris = dataset({nominal(species),'species'},...
              {meas,'SL','SW','PL','PW'},...
              'ObsNames',NameObs);

get(iris)
Description: ''
Units: {}
DimNames: {'Observations' 'Variables'}
UserData: []
ObsNames: {150x1 cell}
VarNames: {'species' 'SL' 'SW' 'PL' 'PW'}

ON = get(iris,'ObsNames');
ON(1:3)
```

```
ans =  
  'Obs1'  
  'Obs2'  
  'Obs3'
```

See Also

set | summary

categorical.getlabels

Purpose Access categorical array labels

Syntax `labels = getlabels(A)`

Description `labels = getlabels(A)` returns the labels of the levels in the categorical array `A` as a cell array of strings `labels`. For ordinal `A`, the labels are returned in the order of the levels.

Examples **Example 1**

Display levels in a nominal and an ordinal array:

```
standings = nominal({'Leafs','Canadiens','Bruins'});
getlabels(standings)
ans =
    'Bruins'    'Canadiens'    'Leafs'
```

```
standings = ordinal(1:3,{'Leafs','Canadiens','Bruins'});
getlabels(standings)
ans =
    'Leafs'    'Canadiens'    'Bruins'
```

Example 2

Display age groups containing data in `hospital.mat`:

```
load hospital
edges = 0:10:100;
labels = strcat(num2str((0:10:90)','%d'),{'s'});
AgeGroup = ordinal(hospital.Age,labels,[],edges);
AgeGroup = droplevels(AgeGroup);
getlabels(AgeGroup)
ans =
    '20s'    '30s'    '40s'    '50s'
```

See Also `getlevels` | `setlabels`

Purpose Get categorical array levels

Syntax `S = getlevels(A)`

Description `S = getlevels(A)` returns the levels for the categorical array `A`. `S` is a vector with the same type as `A`.

See Also `getlabels`

gevcdf

Purpose	Generalized extreme value cumulative distribution function
Syntax	$P = \text{gevcdf}(X, k, \text{sigma}, \mu)$
Description	<p>$P = \text{gevcdf}(X, k, \text{sigma}, \mu)$ returns the cdf of the generalized extreme value (GEV) distribution with shape parameter k, scale parameter sigma, and location parameter, μ, evaluated at the values in X. The size of P is the common size of the input arguments. A scalar input functions as a constant matrix of the same size as the other inputs.</p> <p>Default values for k, sigma, and μ are 0, 1, and 0, respectively.</p> <p>When $k < 0$, the GEV is the type III extreme value distribution. When $k > 0$, the GEV distribution is the type II, or Frechet, extreme value distribution. If w has a Weibull distribution as computed by the <code>wblcdf</code> function, then $-w$ has a type III extreme value distribution and $1/w$ has a type II extreme value distribution. In the limit as k approaches 0, the GEV is the mirror image of the type I extreme value distribution as computed by the <code>evcdf</code> function.</p> <p>The mean of the GEV distribution is not finite when $k \geq 1$, and the variance is not finite when $k \geq 1/2$. The GEV distribution has positive density only for values of X such that $k*(X-\mu)/\text{sigma} > -1$.</p>
References	<p>[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. <i>Modelling Extremal Events for Insurance and Finance</i>. New York: Springer, 1997.</p> <p>[2] Kotz, S., and S. Nadarajah. <i>Extreme Value Distributions: Theory and Applications</i>. London: Imperial College Press, 2000.</p>
See Also	<code>cdf</code> <code>gevpdf</code> <code>gevinv</code> <code>gevstat</code> <code>gevfit</code> <code>gevlike</code> <code>gevrnd</code>
How To	• “Generalized Extreme Value Distribution” on page B-45

Purpose

Generalized extreme value parameter estimates

Syntax

```
parmhat = gevfit(X)
[parmhat,parmci] = gevfit(X)
[parmhat,parmci] = gevfit(X,alpha)
[...] = gevfit(X,alpha,options)
```

Description

`parmhat = gevfit(X)` returns maximum likelihood estimates of the parameters for the generalized extreme value (GEV) distribution given the data in X. `parmhat(1)` is the shape parameter, `k`, `parmhat(2)` is the scale parameter, `sigma`, and `parmhat(3)` is the location parameter, `mu`.

`[parmhat,parmci] = gevfit(X)` returns 95% confidence intervals for the parameter estimates.

`[parmhat,parmci] = gevfit(X,alpha)` returns $100(1-\alpha)\%$ confidence intervals for the parameter estimates.

`[...] = gevfit(X,alpha,options)` specifies control parameters for the iterative algorithm used to compute ML estimates. This argument can be created by a call to `statset`. See `statset('gevfit')` for parameter names and default values. Pass in `[]` for `alpha` to use the default values.

When $k < 0$, the GEV is the type III extreme value distribution. When $k > 0$, the GEV distribution is the type II, or Frechet, extreme value distribution. If w has a Weibull distribution as computed by the `wblfit` function, then $-w$ has a type III extreme value distribution and $1/w$ has a type II extreme value distribution. In the limit as k approaches 0, the GEV is the mirror image of the type I extreme value distribution as computed by the `evfit` function.

The mean of the GEV distribution is not finite when $k \geq 1$, and the variance is not finite when $k \geq 1/2$. The GEV distribution is defined for $k*(X-\mu)/\sigma > -1$.

References

[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also

mle | gevlike | gevpdf | gevCDF | gevinv | gevstat | gevrnd

How To

- “Generalized Extreme Value Distribution” on page B-45

Purpose	Generalized extreme value inverse cumulative distribution function
Syntax	<code>X = gevinv(P,k,sigma,mu)</code>
Description	<p><code>X = gevinv(P,k,sigma,mu)</code> returns the inverse cdf of the generalized extreme value (GEV) distribution with shape parameter <code>k</code>, scale parameter <code>sigma</code>, and location parameter <code>mu</code>, evaluated at the values in <code>P</code>. The size of <code>X</code> is the common size of the input arguments. A scalar input functions as a constant matrix of the same size as the other inputs.</p> <p>Default values for <code>k</code>, <code>sigma</code>, and <code>mu</code> are 0, 1, and 0, respectively.</p> <p>When $k < 0$, the GEV is the type III extreme value distribution. When $k > 0$, the GEV distribution is the type II, or Frechet, extreme value distribution. If w has a Weibull distribution as computed by the <code>wblinv</code> function, then $-w$ has a type III extreme value distribution and $1/w$ has a type II extreme value distribution. In the limit as k approaches 0, the GEV is the mirror image of the type I extreme value distribution as computed by the <code>evinv</code> function.</p> <p>The mean of the GEV distribution is not finite when $k \geq 1$, and the variance is not finite when $k \geq 1/2$. The GEV distribution has positive density only for values of X such that $k*(X-\mu)/\sigma > -1$.</p>
References	<p>[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. <i>Modelling Extremal Events for Insurance and Finance</i>. New York: Springer, 1997.</p> <p>[2] Kotz, S., and S. Nadarajah. <i>Extreme Value Distributions: Theory and Applications</i>. London: Imperial College Press, 2000.</p>
See Also	<code>icdf</code> <code>gevcdf</code> <code>gevpdf</code> <code>gevstat</code> <code>gevfit</code> <code>gevlike</code> <code>gevrnd</code>
How To	<ul style="list-style-type: none">• “Generalized Extreme Value Distribution” on page B-45

gevlike

Purpose	Generalized extreme value negative log-likelihood
Syntax	<pre>nlogL = gevlike(params,data) [nlogL,ACOV] = gevlike(params,data)</pre>
Description	<p><code>nlogL = gevlike(params,data)</code> returns the negative of the log-likelihood <code>nlogL</code> for the generalized extreme value (GEV) distribution, evaluated at parameters <code>params</code>. <code>params(1)</code> is the shape parameter, <code>k</code>, <code>params(2)</code> is the scale parameter, <code>sigma</code>, and <code>params(3)</code> is the location parameter, <code>mu</code>.</p> <p><code>[nlogL,ACOV] = gevlike(params,data)</code> returns the inverse of Fisher's information matrix, <code>ACOV</code>. If the input parameter values in <code>params</code> are the maximum likelihood estimates, the diagonal elements of <code>ACOV</code> are their asymptotic variances. <code>ACOV</code> is based on the observed Fisher's information, not the expected information.</p> <p>When $k < 0$, the GEV is the type III extreme value distribution. When $k > 0$, the GEV distribution is the type II, or Frechet, extreme value distribution. If w has a Weibull distribution as computed by the <code>wbllike</code> function, then $-w$ has a type III extreme value distribution and $1/w$ has a type II extreme value distribution. In the limit as k approaches 0, the GEV is the mirror image of the type I extreme value distribution as computed by the <code>evlike</code> function.</p> <p>The mean of the GEV distribution is not finite when $k \geq 1$, and the variance is not finite when $k \geq 1/2$. The GEV distribution has positive density only for values of X such that $k*(X-\mu)/\sigma > -1$.</p>
References	<p>[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. <i>Modelling Extremal Events for Insurance and Finance</i>. New York: Springer, 1997.</p> <p>[2] Kotz, S., and S. Nadarajah. <i>Extreme Value Distributions: Theory and Applications</i>. London: Imperial College Press, 2000.</p>
See Also	<code>gevfit</code> <code>gevpdf</code> <code>gevcdf</code> <code>gevinv</code> <code>gevstat</code> <code>gevrnd</code>
How To	<ul style="list-style-type: none">• “Generalized Extreme Value Distribution” on page B-45

Purpose	Generalized extreme value probability density function
Syntax	$Y = \text{gevpdf}(X, k, \text{sigma}, \mu)$
Description	<p>$Y = \text{gevpdf}(X, k, \text{sigma}, \mu)$ returns the pdf of the generalized extreme value (GEV) distribution with shape parameter k, scale parameter sigma, and location parameter, μ, evaluated at the values in X. The size of Y is the common size of the input arguments. A scalar input functions as a constant matrix of the same size as the other inputs.</p> <p>Default values for k, sigma, and μ are 0, 1, and 0, respectively.</p> <p>When $k < 0$, the GEV is the type III extreme value distribution. When $k > 0$, the GEV distribution is the type II, or Frechet, extreme value distribution. If w has a Weibull distribution as computed by the <code>wblpdf</code> function, then $-w$ has a type III extreme value distribution and $1/w$ has a type II extreme value distribution. In the limit as k approaches 0, the GEV is the mirror image of the type I extreme value distribution as computed by the <code>evcdf</code> function.</p> <p>The mean of the GEV distribution is not finite when $k \geq 1$, and the variance is not finite when $k \geq 1/2$. The GEV distribution has positive density only for values of X such that $k*(X-\mu)/\text{sigma} > -1$.</p>
References	<p>[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. <i>Modelling Extremal Events for Insurance and Finance</i>. New York: Springer, 1997.</p> <p>[2] Kotz, S., and S. Nadarajah. <i>Extreme Value Distributions: Theory and Applications</i>. London: Imperial College Press, 2000.</p>
See Also	<code>pdf</code> <code>gevcdf</code> <code>gevinv</code> <code>gevstat</code> <code>gevfit</code> <code>gevlike</code> <code>gevrnd</code>
How To	<ul style="list-style-type: none">• “Generalized Extreme Value Distribution” on page B-45

Purpose Generalized extreme value random numbers

Syntax
R = gevrnd(k,sigma,mu)
R = gevrnd(k,sigma,mu,m,n,...)
R = gevrnd(k,sigma,mu,[m,n,...])

Description R = gevrnd(k,sigma,mu) returns an array of random numbers chosen from the generalized extreme value (GEV) distribution with shape parameter k, scale parameter sigma, and location parameter, mu. The size of R is the common size of the input arguments if all are arrays. If any parameter is a scalar, the size of R is the size of the other parameters.

R = gevrnd(k,sigma,mu,m,n,...) or R = gevrnd(k,sigma,mu,[m,n,...]) generates an m-by-n-by-... array containing random numbers from the GEV distribution with parameters k, sigma, and mu. The k, sigma, mu parameters can each be scalars or arrays of the same size as R.

When $k < 0$, the GEV is the type III extreme value distribution. When $k > 0$, the GEV distribution is the type II, or Frechet, extreme value distribution. If w has a Weibull distribution as computed by the wblrnd function, then -w has a type III extreme value distribution and 1/w has a type II extreme value distribution. In the limit as k approaches 0, the GEV is the mirror image of the type I extreme value distribution as computed by the evrnd function.

The mean of the GEV distribution is not finite when $k \geq 1$, and the variance is not finite when $k \geq 1/2$. The GEV distribution has positive density only for values of X such that $k*(X-mu)/sigma > -1$.

References

[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also random | gevpdf | gevCDF | gevinv | gevstat | gevfit | gevlike

How To

- “Generalized Extreme Value Distribution” on page B-45

gevstat

Purpose Generalized extreme value mean and variance

Syntax `[M,V] = gevstat(k,sigma,mu)`

Description `[M,V] = gevstat(k,sigma,mu)` returns the mean of and variance for the generalized extreme value (GEV) distribution with shape parameter `k`, scale parameter `sigma`, and location parameter, `mu`. The sizes of `M` and `V` are the common size of the input arguments. A scalar input functions as a constant matrix of the same size as the other inputs.

Default values for `k`, `sigma`, and `mu` are 0, 1, and 0, respectively.

When $k < 0$, the GEV is the type III extreme value distribution. When $k > 0$, the GEV distribution is the type II, or Frechet, extreme value distribution. If w has a Weibull distribution as computed by the `wblstat` function, then $-w$ has a type III extreme value distribution and $1/w$ has a type II extreme value distribution. In the limit as k approaches 0, the GEV is the mirror image of the type I extreme value distribution as computed by the `evstat` function.

The mean of the GEV distribution is not finite when $k \geq 1$, and the variance is not finite when $k \geq 1/2$. The GEV distribution has positive density only for values of X such that $k*(X-\mu)/\text{sigma} > -1$.

References [1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also `gevpdf` | `gevcdf` | `gevinv` | `gevfit` | `gevlike` | `gevrnd`

How To • “Generalized Extreme Value Distribution” on page B-45

Purpose

Interactively add line to plot

Syntax

```
gline(h)
gline
hline = gline(...)
```

Description

`gline(h)` allows you to draw a line segment in the figure with handle `h` by clicking the pointer at the two endpoints. A rubber-band line tracks the pointer movement.

`gline` with no input arguments defaults to `h = gcf` and draws in the current figure.

`hline = gline(...)` returns the handle `hline` to the line.

Examples

Use `gline` to connect two points in a plot:

```
x = 1:10;

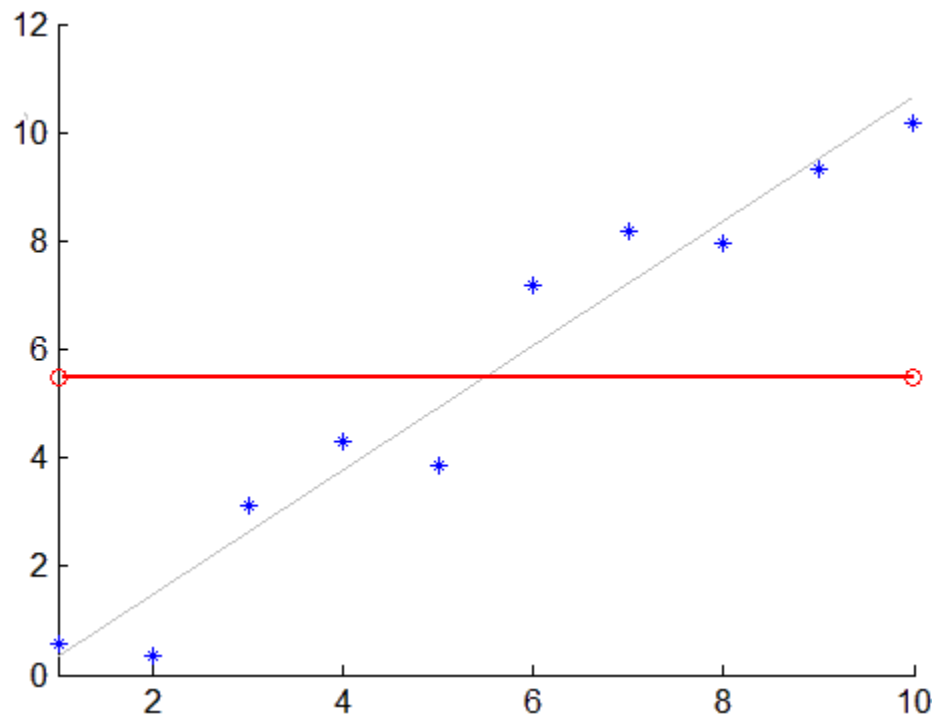
y = x + randn(1,10);
scatter(x,y,25,'b','*')

lsline

mu = mean(y);
hold on
plot([1 10],[mu mu],'ro')

hline = gline; % Connect circles
set(hline,'Color','r')
```

gline



See Also

`refline` | `refcurve` | `lsline`

Purpose

Generalized linear model regression

Syntax

```
b = glmfit(X,y,distr)
b = glmfit(X,y,distr,param1,val1,param2,val2,...)
[b,dev] = glmfit(...)
[b,dev,stats] = glmfit(...)
```

Description

`b = glmfit(X,y,distr)` returns a p -by-1 vector `b` of coefficient estimates for a generalized linear regression of the responses in `y` on the predictors in `X`, using the distribution `distr`. `X` is an n -by- p matrix of p predictors at each of n observations. `distr` can be any of the following strings: 'binomial', 'gamma', 'inverse gaussian', 'normal' (the default), and 'poisson'.

In most cases, `y` is an n -by-1 vector of observed responses. For the binomial distribution, `y` can be a binary vector indicating success or failure at each observation, or a two column matrix with the first column indicating the number of successes for each observation and the second column indicating the number of trials for each observation.

This syntax uses the canonical link (see below) to relate the distribution to the predictors.

Note By default, `glmfit` adds a first column of 1s to `X`, corresponding to a constant term in the model. Do not enter a column of 1s directly into `X`. You can change the default behavior of `glmfit` using the 'constant' parameter, below.

`glmfit` treats NaNs in either `X` or `y` as missing values, and ignores them.

`b = glmfit(X,y,distr,param1,val1,param2,val2,...)` additionally allows you to specify optional parameter name/value pairs to control the model fit. Acceptable parameters are as follows:

Parameter	Value	Description
'link'	'identity', default for the distribution 'normal'	$\mu = Xb$
	'log', default for the distribution 'poisson'	$\log(\mu) = Xb$
	'logit', default for the distribution 'binomial'	$\log(\mu/(1 - \mu)) = Xb$
	'probit'	$\text{norminv}(\mu) = Xb$
	'comploglog'	$\log(-\log(1 - \mu)) = Xb$
	'reciprocal', default for the distribution 'gamma'	$1/\mu = Xb$
	'loglog'	$\log(-\log(\mu)) = Xb$
	p (a number), default for the distribution 'inverse gaussian' (with $p = -2$)	$\mu^p = Xb$
	cell array of the form {FL FD FI}, containing three function handles, created using @, that define the link (FL), the derivative of the link (FD), and the inverse link (FI).	User-specified link function

Parameter	Value	Description
'estdisp'	'on'	Estimates a dispersion parameter for the binomial or Poisson distribution
	'off' (Default for binomial or Poisson distribution)	Uses the theoretical value of 1.0 for those distributions
'offset'	Vector	Used as an additional predictor variable, but with a coefficient value fixed at 1.0
'weights'	Vector of prior weights, such as the inverses of the relative variance of each observation	
'constant'	'on' (default)	Includes a constant term in the model. The coefficient of the constant term is the first element of b .
	'off'	Omit the constant term

`[b,dev] = glmfit(...)` returns `dev`, the deviance of the fit at the solution vector. The deviance is a generalization of the residual sum of squares. It is possible to perform an analysis of deviance to compare several models, each a subset of the other, and to test whether the model with more terms is significantly better than the model with fewer terms.

`[b,dev,stats] = glmfit(...)` returns `dev` and `stats`.

`stats` is a structure with the following fields:

- `beta` — Coefficient estimates `b`
- `dfe` — Degrees of freedom for error
- `s` — Theoretical or estimated dispersion parameter

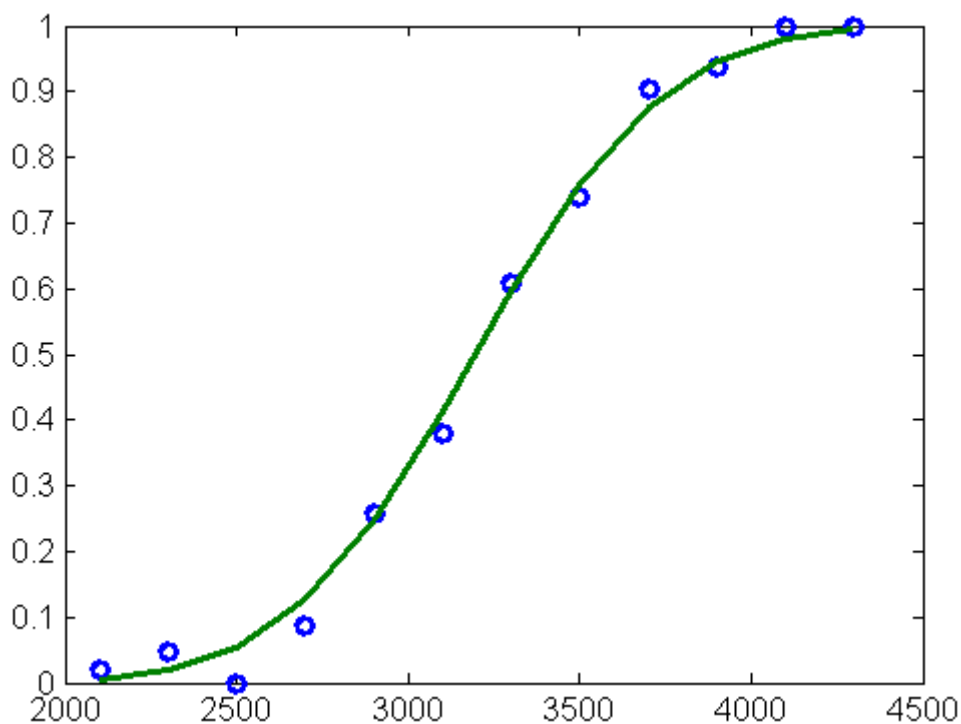
- `sfit` — Estimated dispersion parameter
- `se` — Vector of standard errors of the coefficient estimates `b`
- `coeffcorr` — Correlation matrix for `b`
- `covb` — Estimated covariance matrix for `B`
- `t` — t statistics for `b`
- `p` — p -values for `b`
- `resid` — Vector of residuals
- `residp` — Vector of Pearson residuals
- `residd` — Vector of deviance residuals
- `resida` — Vector of Anscombe residuals

If you estimate a dispersion parameter for the binomial or Poisson distribution, then `stats.s` is set equal to `stats.sfit`. Also, the elements of `stats.se` differ by the factor `stats.s` from their theoretical values.

Examples

Fit a probit regression model for y on x . Each $y(i)$ is the number of successes in $n(i)$ trials.

```
x = [2100 2300 2500 2700 2900 3100 ...  
     3300 3500 3700 3900 4100 4300]';  
n = [48 42 31 34 31 21 23 23 21 16 17 21]';  
y = [1 2 0 3 8 8 14 17 19 15 17 21]';  
b = glmfit(x,[y n],'binomial','link','probit');  
yfit = glmval(b, x,'probit','size', n);  
plot(x, y./n,'o',x,yfit./n,'-', 'LineWidth',2)
```

References

- [1] Dobson, A. J. *An Introduction to Generalized Linear Models*. New York: Chapman & Hall, 1990.
- [2] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*. New York: Chapman & Hall, 1990.
- [3] Collett, D. *Modeling Binary Data*. New York: Chapman & Hall, 2002.

See Also

`glmval` | `regress` | `regstats`

glmval

Purpose Generalized linear model values

Syntax
`yhat = glmval(b,X,link)`
`[yhat,dylo,dyhi] = glmval(b,X,link,stats)`
`[...] = glmval(...,param1,val1,param2,val2,...)`

Description `yhat = glmval(b,X,link)` computes predicted values for the generalized linear model with link function `link` and predictors `X`. Distinct predictor variables should appear in different columns of `X`. `b` is a vector of coefficient estimates as returned by the `glmfit` function. `link` can be any of the strings used as values for the `link` parameter in the `glmfit` function.

Note By default, `glmval` adds a first column of 1s to `X`, corresponding to a constant term in the model. Do not enter a column of 1s directly into `X`. You can change the default behavior of `glmval` using the 'constant' parameter, below.

`[yhat,dylo,dyhi] = glmval(b,X,link,stats)` also computes 95% confidence bounds for the predicted values. When the `stats` structure output of the `glmfit` function is specified, `dylo` and `dyhi` are also returned. `dylo` and `dyhi` define a lower confidence bound of `yhat-dylo`, and an upper confidence bound of `yhat+dyhi`. Confidence bounds are nonsimultaneous, and apply to the fitted curve, not to a new observation.

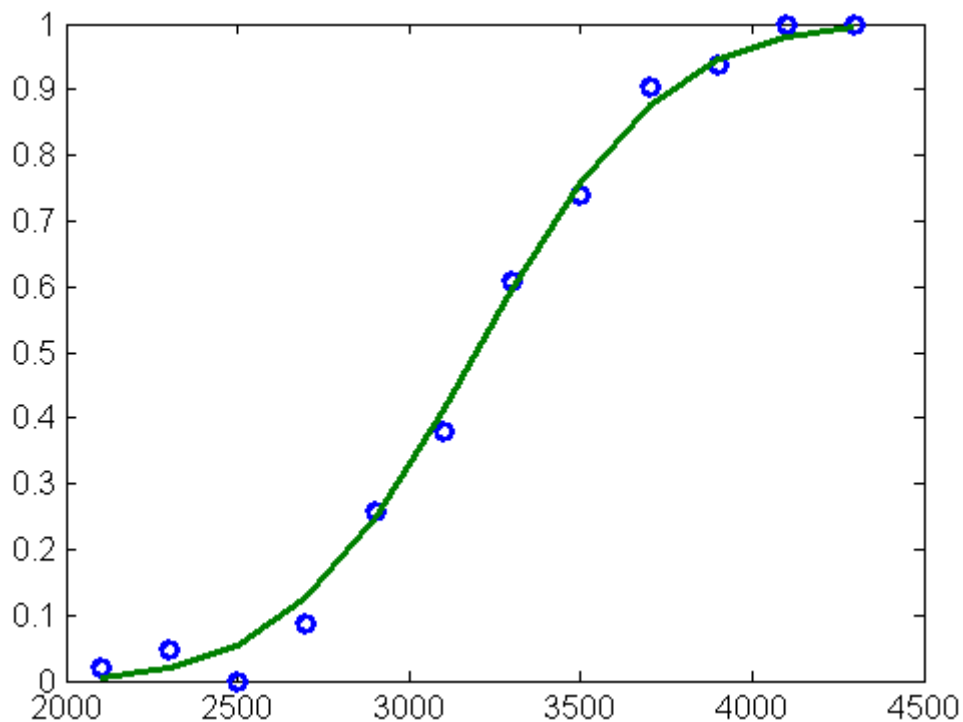
`[...] = glmval(...,param1,val1,param2,val2,...)` specifies optional parameter name/value pairs to control the predicted values. Acceptable parameters are:

Parameter	Value
'confidence' — the confidence level for the confidence bounds	A scalar between 0 and 1
'size' — the size parameter (N) for a binomial model	A scalar, or a vector with one value for each row of X
'offset' — used as an additional predictor variable, but with a coefficient value fixed at 1.0	A vector
'constant'	<ul style="list-style-type: none"> 'on' — Includes a constant term in the model. The coefficient of the constant term is the first element of b. 'off' — Omit the constant term
'simultaneous' — Compute simultaneous confidence intervals (true), or compute non-simultaneous confidence intervals (default false)	true or false

Examples

Fit a probit regression model for y on x. Each y(i) is the number of successes in n(i) trials.

```
x = [2100 2300 2500 2700 2900 3100 ...
     3300 3500 3700 3900 4100 4300]';
n = [48 42 31 34 31 21 23 23 21 16 17 21]';
y = [1 2 0 3 8 8 14 17 19 15 17 21]';
b = glmfit(x,[y n],'binomial','link','probit');
yfit = glmval(b,x,'probit','size',n);
plot(x, y./n,'o',x,yfit./n,'-', 'LineWidth',2)
```



References

- [1] Dobson, A. J. *An Introduction to Generalized Linear Models*. New York: Chapman & Hall, 1990.
- [2] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*. New York: Chapman & Hall, 1990.
- [3] Collett, D. *Modeling Binary Data*. New York: Chapman & Hall, 2002.

See Also

`glmfit`

Purpose

Glyph plot

Syntax

```
glyphplot(X)
glyphplot(X, 'glyph', 'face')
glyphplot(X, 'glyph', 'face', 'features', f)
glyphplot(X, ..., 'grid', [rows, cols])
glyphplot(X, ..., 'grid', [rows, cols], 'page', p)
glyphplot(X, ..., 'centers', C)
glyphplot(X, ..., 'centers', C, 'radius', r)
glyphplot(X, ..., 'obslabels', labels)
glyphplot(X, ..., 'standardize', method)
glyphplot(X, ..., prop1, val1, ...)
h = glyphplot(X, ...)
```

Description

`glyphplot(X)` creates a star plot from the multivariate data in the n -by- p matrix X . Rows of X correspond to observations, columns to variables. A star plot represents each observation as a “star” whose i th spoke is proportional in length to the i th coordinate of that observation. `glyphplot` standardizes X by shifting and scaling each column separately onto the interval $[0, 1]$ before making the plot, and centers the glyphs on a rectangular grid that is as close to square as possible. `glyphplot` treats NaNs in X as missing values, and does not plot the corresponding rows of X . `glyphplot(X, 'glyph', 'star')` is a synonym for `glyphplot(X)`.

`glyphplot(X, 'glyph', 'face')` creates a face plot from X . A face plot represents each observation as a “face,” whose i th facial feature is drawn with a characteristic proportional to the i th coordinate of that observation. The features are described in “Face Features” on page 20-861 Face Features.

`glyphplot(X, 'glyph', 'face', 'features', f)` creates a face plot where the i th element of the index vector f defines which facial feature will represent the i th column of X . f must contain integers from 0 to 17, where 0 indicate that the corresponding column of X should not be plotted. See “Face Features” on page 20-861 for more information.

glyphplot

`glyphplot(X, ..., 'grid', [rows, cols])` organizes the glyphs into a rows-by-cols grid.

`glyphplot(X, ..., 'grid', [rows, cols], 'page', p)` organizes the glyph into one or more pages of a rows-by-cols grid, and displays the page `p`. If `p` is a vector, `glyphplot` displays multiple pages in succession. If `p` is 'all', `glyphplot` displays all pages. If `p` is 'scroll', `glyphplot` displays a single plot with a scrollbar.

`glyphplot(X, ..., 'centers', C)` creates a plot with each glyph centered at the locations in the n -by-2 matrix `C`.

`glyphplot(..., 'centers', C, 'radius', r)` creates a plot with glyphs positioned using `C`, and scale the glyphs so the largest has radius `r`.

`glyphplot(X, ..., 'obslabels', labels)` labels each glyph with the text in the character array or cell array of strings `labels`. By default, the glyphs are labelled 1:N. Use '' for blank labels.

`glyphplot(X, ..., 'standardize', method)` standardizes `X` before making the plot. Choices for `method` are

- 'column' — Maps each column of `X` separately onto the interval $[0,1]$. This is the default.
- 'matrix' — Maps the entire matrix `X` onto the interval $[0,1]$.
- 'PCA' — Transforms `X` to its principal component scores, in order of decreasing eigenvalue, and maps each one onto the interval $[0,1]$.
- 'off' — No standardization. Negative values in `X` may make a star plot uninterpretable.

`glyphplot(X, ..., prop1, val1, ...)` sets properties to the specified property values for all line graphics objects created by `glyphplot`.

`h = glyphplot(X, ...)` returns a matrix of handles to the graphics objects created by `glyphplot`. For a star plot, `h(:,1)` and `h(:,2)` contain handles to the line objects for each star's perimeter and spokes, respectively. For a face plot, `h(:,1)` and `h(:,2)` contain object handles to the lines making up each face and to the pupils, respectively. `h(:,3)` contains handles to the text objects for the labels, if present.

Face Features

The following table describes the correspondence between the columns of the vector f , the value of the 'Features' input parameter, and the facial features of the glyph plot. If X has fewer than 17 columns, unused features are displayed at their default value.

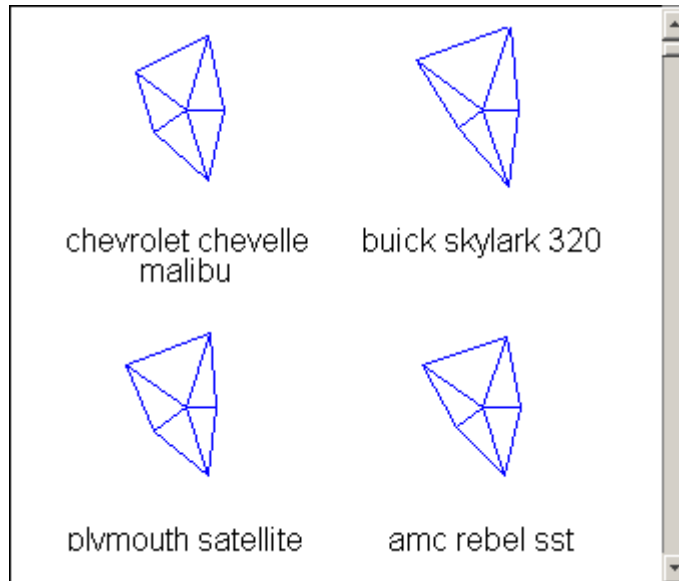
Column	Facial Feature
1	Size of face
2	Forehead/jaw relative arc length
3	Shape of forehead
4	Shape of jaw
5	Width between eyes
6	Vertical position of eyes
7	Height of eyes
8	Width of eyes (this also affects eyebrow width)
9	Angle of eyes (this also affects eyebrow angle)
10	Vertical position of eyebrows
11	Width of eyebrows (relative to eyes)
12	Angle of eyebrows (relative to eyes)
13	Direction of pupils
14	Length of nose
15	Vertical position of mouth
16	Shape of mouth
17	Mouth arc length

Examples

```
load carsmall
X = [Acceleration Displacement Horsepower MPG Weight];
```

glyphplot

```
glyphplot(X, 'standardize', 'column', ...  
          'obslabels', Model, ...  
          'grid', [2 2], ...  
          'page', 'scroll');
```



```
glyphplot(X, 'glyph', 'face', ...  
          'obslabels', Model, ...  
          'grid', [2 3], ...  
          'page', 9);
```




pontiac ventura sj



amc pacer d/i



volkswagen rabbit



datsun b-210



toyota corolla



ford pinto

See Also

[andrewsplot](#) | [parallelcoords](#)

gmdistribution

Purpose Gaussian mixture models

Description An object of the `gmdistribution` class defines a Gaussian mixture distribution, which is a multivariate distribution that consists of a mixture of one or more multivariate Gaussian distribution components. The number of components for a given `gmdistribution` object is fixed. Each multivariate Gaussian component is defined by its mean and covariance, and the mixture is defined by a vector of mixing proportions.

Construction To create a Gaussian mixture distribution by specifying the distribution parameters, use the `gmdistribution` constructor. To fit a Gaussian mixture distribution model to data, use `gmdistribution.fit`.

<code>fit</code>	Gaussian mixture parameter estimates
<code>gmdistribution</code>	Construct Gaussian mixture distribution

Properties All objects of the class have the properties listed in the following table.

<code>CovType</code>	Type of covariance matrices
<code>DistName</code>	Type of distribution
<code>Mu</code>	Input matrix of means μ
<code>NComponents</code>	Number k of mixture components
<code>NDimensions</code>	Dimension d of multivariate Gaussian distributions
<code>PComponents</code>	Input vector of mixing proportions
<code>SharedCov</code>	true if all covariance matrices are restricted to be the same
<code>Sigma</code>	Input array of covariances

Objects constructed with `fit` have the additional properties listed in the following table.

AIC	Akaike Information Criterion
BIC	Bayes Information Criterion
Converged	Determine if algorithm converged
Iters	Number of iterations
NlogL	Negative of log-likelihood
RegV	Value of 'Regularize' parameter

Methods

<code>cdf</code>	Cumulative distribution function for Gaussian mixture distribution
<code>cluster</code>	Construct clusters from Gaussian mixture distribution
<code>disp</code>	Display Gaussian mixture distribution object
<code>display</code>	Display Gaussian mixture distribution object
<code>fit</code>	Gaussian mixture parameter estimates
<code>mahal</code>	Mahalanobis distance to component means
<code>pdf</code>	Probability density function for Gaussian mixture distribution
<code>posterior</code>	Posterior probabilities of components
<code>random</code>	Random numbers from Gaussian mixture distribution

subsasgn	Subscripted reference for Gaussian mixture distribution object
suboref	Subscripted reference for Gaussian mixture distribution object

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

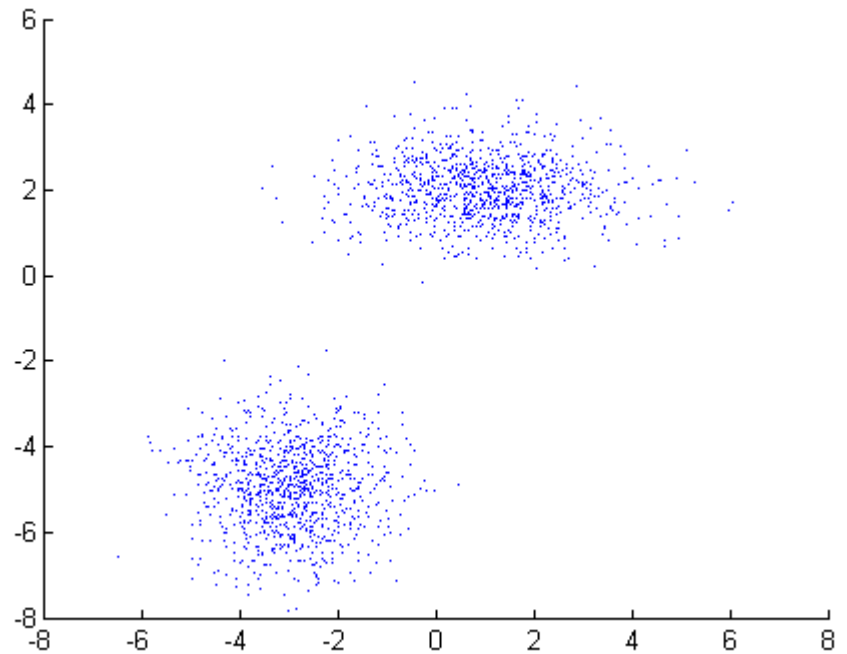
Fit a Gaussian Mixture Model

Generate data from a mixture of two bivariate Gaussian distributions using the `mvnrnd` function. Fit the resulting data.

Generate the data using 1000 points from each distribution.

```
MU1 = [1 2];  
SIGMA1 = [2 0; 0 .5];  
MU2 = [-3 -5];  
SIGMA2 = [1 0; 0 1];  
X = [mvnrnd(MU1,SIGMA1,1000);mvnrnd(MU2,SIGMA2,1000)];
```

```
scatter(X(:,1),X(:,2),10,'.')  
hold on
```



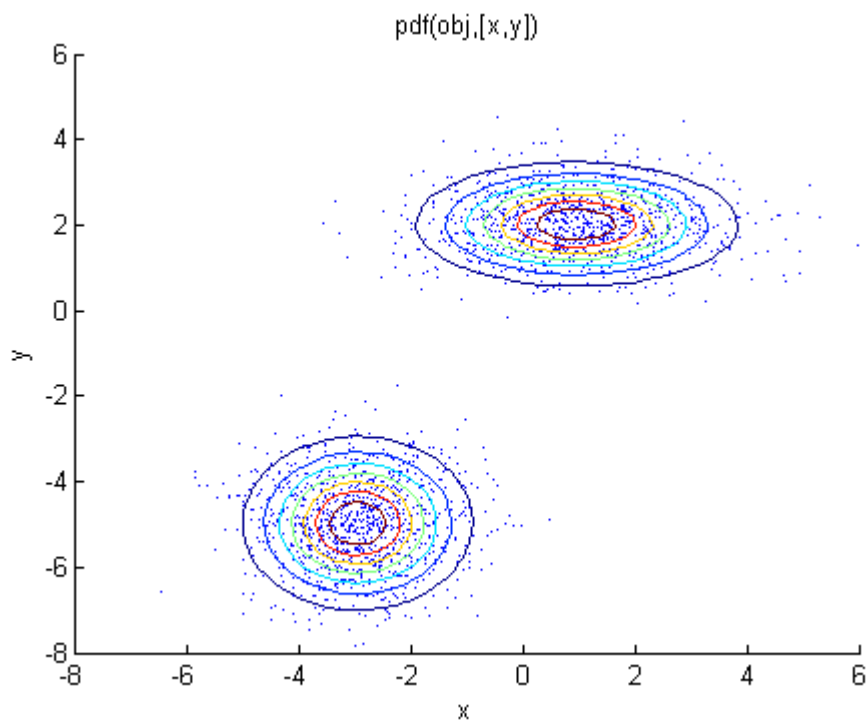
Fit a two-component Gaussian mixture model.

```
options = statset('Display','final');  
obj = gmdistribution.fit(X,2,'Options',options);
```

```
18 iterations, log-likelihood = -7058.35
```

```
h = ezcontour(@(x,y)pdf(obj,[x y]),[-8 6],[-8 6]);
```

gmdistribution



References

- [1] McLachlan, G., and D. Peel. *Finite Mixture Models*. Hoboken, NJ: John Wiley & Sons, Inc., 2000.

See Also `gmdistribution.fit`

Related Examples

- “Normal Distribution” on page B-96

Concepts

Purpose Construct Gaussian mixture distribution

Syntax `obj = gmdistribution(mu,sigma,p)`

Description `obj = gmdistribution(mu,sigma,p)` constructs an object `obj` of the `gmdistribution` class defining a Gaussian mixture distribution.

`mu` is a k -by- d matrix specifying the d -dimensional mean of each of the k components.

`sigma` specifies the covariance of each component. The size of `sigma` is:

- d -by- d -by- k if there are no restrictions on the form of the covariance. In this case, `sigma(:, :, I)` is the covariance of component I .
- 1-by- d -by- k if the covariance matrices are restricted to be diagonal, but not restricted to be same across components. In this case, `sigma(:, :, I)` contains the diagonal elements of the covariance of component I .
- d -by- d matrix if the covariance matrices are restricted to be the same across components, but not restricted to be diagonal. In this case, `sigma` is the pooled estimate of covariance.
- 1-by- d if the covariance matrices are restricted to be diagonal and the same across components. In this case, `sigma` contains the diagonal elements of the pooled estimate of covariance.

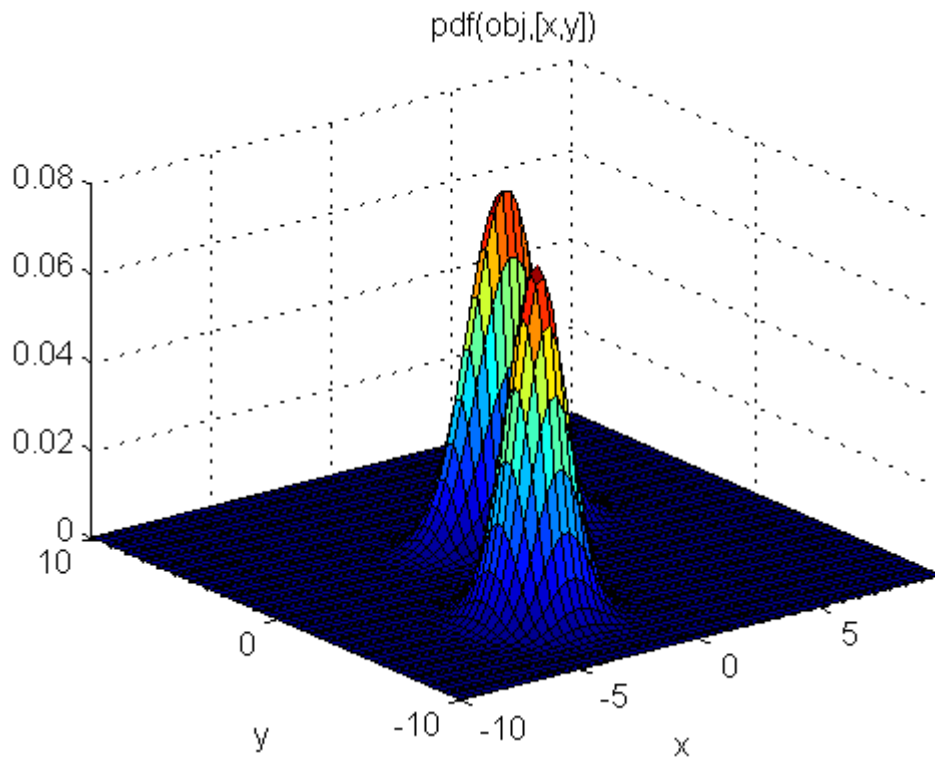
`p` is an optional 1-by- k vector specifying the mixing proportions of each component. If `p` does not sum to 1, `gmdistribution` normalizes it. The default is equal proportions.

Examples Create a `gmdistribution` object defining a two-component mixture of bivariate Gaussian distributions:

```
mu = [1 2; -3 -5];  
sigma = cat(3, [2 0; 0 .5], [1 0; 0 1]);  
p = ones(1,2)/2;  
obj = gmdistribution(mu,sigma,p);
```

gmdistribution

```
ezsurf(@(x,y)pdf(obj,[x y]),[-10 10],[-10 10])
```



References

[1] McLachlan, G., and D. Peel. *Finite Mixture Models*. Hoboken, NJ: John Wiley & Sons, Inc., 2000.

See Also

[fit](#) | [pdf](#) | [cdf](#) | [random](#) | [cluster](#) | [posterior](#) | [mahal](#)

Purpose Add case names to plot

Syntax

```
gname(cases)
gname
h = gname(cases,line_handle)
```

Description `gname(cases)` displays a figure window and waits for you to press a mouse button or a keyboard key. The input argument `cases` is a character array or a cell array of strings, in which each row of the character array or each element of the cell array contains the case name of a point. Moving the mouse over the graph displays a pair of cross-hairs. If you position the cross-hairs near a point with the mouse and click once, the graph displays the label corresponding to that point. Alternatively, you can click and drag the mouse to create a rectangle around several points. When you release the mouse button, the graph displays the labels for all points in the rectangle. Right-click a point to remove its label. When you are done labelling points, press the **Enter** or **Escape** key to stop labeling.

`gname` with no arguments labels each case with its case number.

`cases` typically contains unique case names for each point, and is a cell array of strings or a character matrix with each row representing a name. `cases` can also be any grouping variable, which `gname` converts to labels.

`h = gname(cases,line_handle)` returns a vector of handles to the text objects on the plot. Use the scalar `line_handle` to identify the correct line if there is more than one line object on the plot.

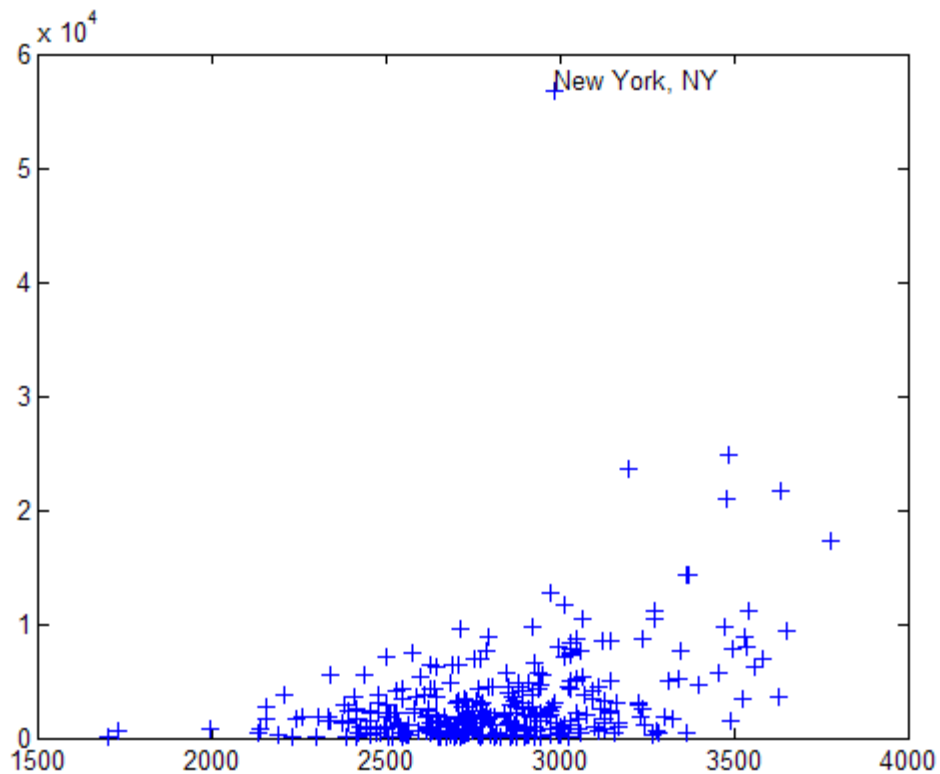
You can use `gname` to label plots created by the `plot`, `scatter`, `gscatter`, `plotmatrix`, and `gplotmatrix` functions.

Examples This example uses the city ratings data sets to find out which cities are the best and worst for education and the arts.

```
load cities
education = ratings(:,6);
arts = ratings(:,7);
```

gname

```
plot(education, arts, '+' )  
gname(names)
```



Click the point at the top of the graph to display its label, “New York.”

See Also

`gtext` | `gscatter` | `gplotmatrix`

Purpose	Generalized Pareto cumulative distribution function
Syntax	<code>P = gpcdf(X,K,sigma,theta)</code>
Description	<p><code>P = gpcdf(X,K,sigma,theta)</code> returns the cdf of the generalized Pareto (GP) distribution with the tail index (shape) parameter <code>K</code>, scale parameter <code>sigma</code>, and threshold (location) parameter, <code>theta</code>, evaluated at the values in <code>X</code>. The size of <code>P</code> is the common size of the input arguments. A scalar input functions as a constant matrix of the same size as the other inputs.</p> <p>Default values for <code>K</code>, <code>sigma</code>, and <code>theta</code> are 0, 1, and 0, respectively.</p> <p>When <code>K = 0</code> and <code>theta = 0</code>, the GP is equivalent to the exponential distribution. When <code>K > 0</code> and <code>theta = sigma/K</code>, the GP is equivalent to the Pareto distribution. The mean of the GP is not finite when $K \geq 1$, and the variance is not finite when $K \geq 1/2$. When $K \geq 0$, the GP has positive density for</p> <p><code>X > theta</code>, or, when</p> $K < 0, 0 \leq \frac{X - \theta}{\sigma} \leq -\frac{1}{K}.$
References	<p>[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. <i>Modelling Extremal Events for Insurance and Finance</i>. New York: Springer, 1997.</p> <p>[2] Kotz, S., and S. Nadarajah. <i>Extreme Value Distributions: Theory and Applications</i>. London: Imperial College Press, 2000.</p>
See Also	<code>cdf</code> <code>gppdf</code> <code>gpinv</code> <code>gpstat</code> <code>gpfit</code> <code>gplike</code> <code>gprnd</code>
How To	<ul style="list-style-type: none"> • “Generalized Pareto Distribution” on page B-50

Purpose Generalized Pareto parameter estimates

Syntax

```
parmhat = gpfif(X)  
[parmhat,parmci] = gpfif(X)  
[parmhat,parmci] = gpfif(X,alpha)  
[...] = gpfif(X,alpha,options)
```

Description `parmhat = gpfif(X)` returns maximum likelihood estimates of the parameters for the two-parameter generalized Pareto (GP) distribution given the data in `X`. `parmhat(1)` is the tail index (shape) parameter, `K` and `parmhat(2)` is the scale parameter, `sigma`. `gpfif` does not fit a threshold (location) parameter.

`[parmhat,parmci] = gpfif(X)` returns 95% confidence intervals for the parameter estimates.

`[parmhat,parmci] = gpfif(X,alpha)` returns $100(1-\text{alpha})\%$ confidence intervals for the parameter estimates.

`[...] = gpfif(X,alpha,options)` specifies control parameters for the iterative algorithm used to compute ML estimates. This argument can be created by a call to `statset`. See `statset('gpfif')` for parameter names and default values.

Other functions for the generalized Pareto, such as `gpcdf` allow a threshold parameter, `theta`. However, `gpfif` does not estimate `theta`. It is assumed to be known, and subtracted from `X` before calling `gpfif`.

When `K = 0` and `theta = 0`, the GP is equivalent to the exponential distribution. When `K > 0` and `theta = sigma/K`, the GP is equivalent to the Pareto distribution. The mean of the GP is not finite when $K \geq 1$, and the variance is not finite when $K \geq 1/2$. When $K \geq 0$, the GP has positive density for

`X > theta`, or, when

$$0 \leq \frac{X - \theta}{\sigma} \leq -\frac{1}{K}$$

References

[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also

mle | gplike | gppdf | gpcdf | gpinv | gpstat | gprnd

How To

- “Generalized Pareto Distribution” on page B-50

gpinv

Purpose Generalized Pareto inverse cumulative distribution function

Syntax `X = gpinv(P,K,sigma,theta)`

Description `X = gpinv(P,K,sigma,theta)` returns the inverse cdf for a generalized Pareto (GP) distribution with tail index (shape) parameter `K`, scale parameter `sigma`, and threshold (location) parameter `theta`, evaluated at the values in `P`. The size of `X` is the common size of the input arguments. A scalar input functions as a constant matrix of the same size as the other inputs.

Default values for `K`, `sigma`, and `theta` are 0, 1, and 0, respectively.

When `K = 0` and `theta = 0`, the GP is equivalent to the exponential distribution. When `K > 0` and `theta = sigma/K`, the GP is equivalent to the Pareto distribution. The mean of the GP is not finite when $K \geq 1$, and the variance is not finite when $K \geq 1/2$. When $K \geq 0$, the GP has positive density for

`X > theta`, or, when

$$K < 0, 0 \leq \frac{X - \theta}{\sigma} \leq -\frac{1}{K}.$$

References [1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also `icdf` | `gpcdf` | `gppdf` | `gpstat` | `gpfit` | `gplike` | `gprnd`

How To • “Generalized Pareto Distribution” on page B-50

Purpose	Generalized Pareto negative log-likelihood
Syntax	<code>nlogL = gplike(params,data)</code> <code>[nlogL,ACOV] = gplike(params,data)</code>
Description	<p><code>nlogL = gplike(params,data)</code> returns the negative of the log-likelihood <code>nlogL</code> for the two-parameter generalized Pareto (GP) distribution, evaluated at parameters <code>params</code>. <code>params(1)</code> is the tail index (shape) parameter, <code>K</code>, <code>params(2)</code> is the scale parameter, <code>sigma</code>, and <code>params(3)</code> is the threshold (location) parameter, <code>mu</code>.</p> <p><code>[nlogL,ACOV] = gplike(params,data)</code> returns the inverse of Fisher's information matrix, <code>ACOV</code>. If the input parameter values in <code>params</code> are the maximum likelihood estimates, the diagonal elements of <code>ACOV</code> are their asymptotic variances. <code>ACOV</code> is based on the observed Fisher's information, not the expected information.</p> <p>When <code>K = 0</code> and <code>theta = 0</code>, the GP is equivalent to the exponential distribution. When <code>K > 0</code> and <code>theta = sigma/K</code>, the GP is equivalent to the Pareto distribution. The mean of the GP is not finite when $K \geq 1$, and the variance is not finite when $K \geq 1/2$. When $K \geq 0$, the GP has positive density for</p> <p>$X > \text{theta}$, or, when</p> $K < 0, 0 \leq \frac{X - \theta}{\sigma} \leq -\frac{1}{K}.$
References	<p>[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. <i>Modelling Extremal Events for Insurance and Finance</i>. New York: Springer, 1997.</p> <p>[2] Kotz, S., and S. Nadarajah. <i>Extreme Value Distributions: Theory and Applications</i>. London: Imperial College Press, 2000.</p>
See Also	<code>gpfit</code> <code>gppdf</code> <code>gpcdf</code> <code>gpinv</code> <code>gpstat</code> <code>gprnd</code>
How To	<ul style="list-style-type: none"> • “Generalized Pareto Distribution” on page B-50

Purpose Generalized Pareto probability density function

Syntax `P = gppdf(X,K,sigma,theta)`

Description `P = gppdf(X,K,sigma,theta)` returns the pdf of the generalized Pareto (GP) distribution with the tail index (shape) parameter `K`, scale parameter `sigma`, and threshold (location) parameter, `theta`, evaluated at the values in `X`. The size of `P` is the common size of the input arguments. A scalar input functions as a constant matrix of the same size as the other inputs.

Default values for `K`, `sigma`, and `theta` are 0, 1, and 0, respectively.

When `K = 0` and `theta = 0`, the GP is equivalent to the exponential distribution. When `K > 0` and `theta = sigma/K`, the GP is equivalent to the Pareto distribution. The mean of the GP is not finite when $K \geq 1$, and the variance is not finite when $K \geq 1/2$. When $K \geq 0$, the GP has positive density for

$X > \theta$, or, when

$$K < 0, 0 \leq \frac{X - \theta}{\sigma} \leq -\frac{1}{K}.$$

References [1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also `pdf` | `gpcdf` | `gpinv` | `gpstat` | `gpfit` | `gplike` | `gprnd`

How To • “Generalized Pareto Distribution” on page B-50

Purpose

Matrix of scatter plots by group

Syntax

```
gplotmatrix(x,y,group)
gplotmatrix(x,y,group,clr,sym,siz)
gplotmatrix(x,y,group,clr,sym,siz,doleg)
gplotmatrix(x,y,group,clr,sym,siz,doleg,dispopt)
gplotmatrix(x,y,group,clr,sym,siz,doleg,dispopt,xnam,ynam)
[h,ax,bigax] = gplotmatrix(...)
```

Description

`gplotmatrix(x,y,group)` creates a matrix of scatter plots. Each individual set of axes in the resulting figure contains a scatter plot of a column of `x` against a column of `y`. All plots are grouped by the grouping variable `group`.

`x` and `y` are matrices with the same number of rows. If `x` has p columns and `y` has q columns, the figure contains a p -by- q matrix of scatter plots. If you omit `y` or specify it as the empty matrix, `[]`, `gplotmatrix` creates a square matrix of scatter plots of columns of `x` against each other.

`group` is a grouping variable that can be a categorical variable, vector, string array, or cell array of strings. `group` must have the same number of rows as `x` and `y`. Points with the same value of `group` are placed in the same group, and appear on the graph with the same marker and color. Alternatively, `group` can be a cell array containing several grouping variables (such as `{g1 g2 g3}`); in that case, observations are in the same group if they have common values of all grouping variables.

`gplotmatrix(x,y,group,clr,sym,siz)` specifies the color, marker type, and size for each group. `clr` is a string array of colors recognized by the `plot` function. The default for `clr` is `'bgrcmyk'`. `sym` is a string array of symbols recognized by the `plot` command, with the default value `'.'`. `siz` is a vector of sizes, with the default determined by the `DefaultLineMarkerSize` property. If you do not specify enough values for all groups, `gplotmatrix` cycles through the specified values as needed.

`gplotmatrix(x,y,group,clr,sym,siz,doleg)` controls whether a legend is displayed on the graph (`doleg` is `'on'`, the default) or not (`doleg` is `'off'`).

`gplotmatrix(x,y,group,clr,sym,siz,doleg,dispopt)` controls what appears along the diagonal of a plot matrix of *y* versus *x*. Allowable values are 'none', to leave the diagonals blank, 'hist', to plot histograms, or 'variable', to write the variable names. `gplotmatrix` displays histograms along the diagonal only when there is only one variable (i.e., `gplotmatrix(x,[],[],[],[],[],[], 'hist')`).

`gplotmatrix(x,y,group,clr,sym,siz,doleg,dispopt,xnam,yname)` specifies the names of the columns in the *x* and *y* arrays. These names are used to label the *x*- and *y*-axes. *xname* and *yname* must be character arrays or cell arrays of strings, with one name for each column of *x* and *y*, respectively.

`[h,ax,bigax] = gplotmatrix(...)` returns three arrays of handles. *h* is an array of handles to the lines on the graphs. The array's third dimension corresponds to groups in *G*. *ax* is a matrix of handles to the axes of the individual plots. If *dispopt* is 'hist', *ax* contains one extra row of handles to invisible axes in which the histograms are plotted. *bigax* is a handle to big (invisible) axes framing the entire plot matrix. *bigax* is fixed to point to the current axes, so a subsequent `title`, `xlabel`, or `ylabel` command will produce labels that are centered with respect to the entire plot matrix.

Examples

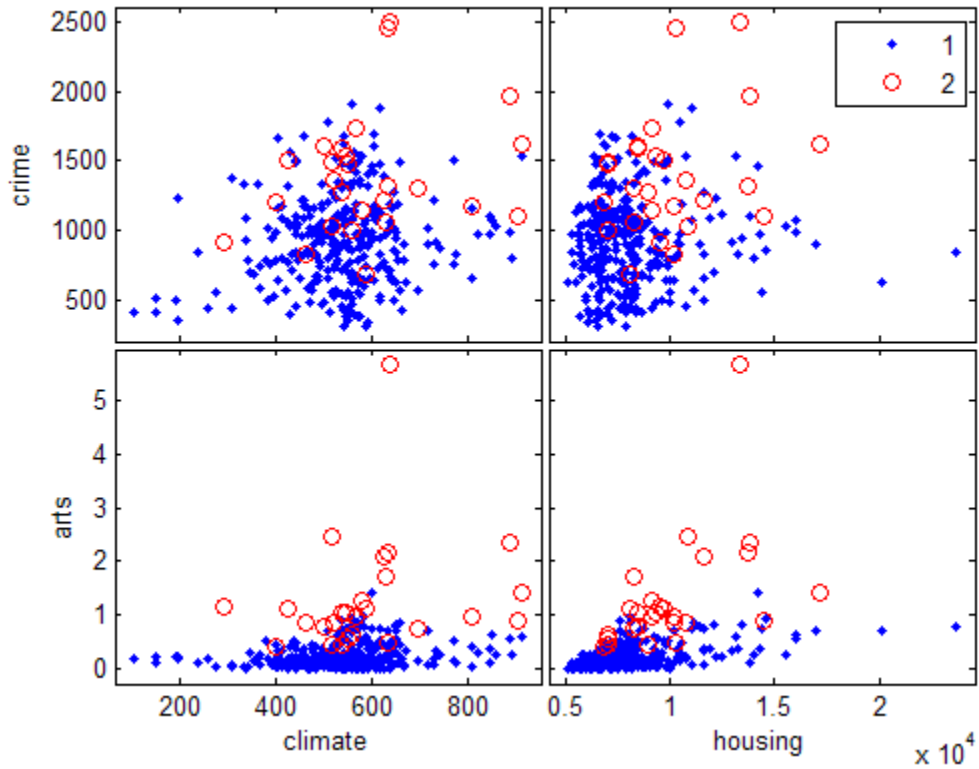
Load the cities data. The ratings array has ratings of the cities in nine categories (category names are in the array `categories`). `group` is a code whose value is 2 for the largest cities. You can make scatter plots of the first three categories against the other four, grouped by the city size code:

```
load discrim
gplotmatrix(ratings(:,1:2),ratings(:,[4 7]),group)
```

The output figure (not shown) has an array of graphs with each city group represented by a different color. The graphs are a little easier to read if you specify colors and plotting symbols, label the axes with the rating categories, and move the legend off the graphs:

```
gplotmatrix(ratings(:,1:2),ratings(:,[4 7]),group,...
```

```
'br', '.o', [], 'on', '', categories(1:2,:), ...
categories([4 7],:))
```



See Also

grpstats | gscatter | plotmatrix

How To

- “Grouping Variables” on page 2-72

gprnd

Purpose Generalized Pareto random numbers

Syntax
R = gprnd(K, sigma, theta)
R = gprnd(K, sigma, theta, m, n, ...)
R = gprnd(K, sigma, theta, [m, n, ...])

Description R = gprnd(K, sigma, theta) returns an array of random numbers chosen from the generalized Pareto (GP) distribution with tail index (shape) parameter K, scale parameter sigma, and threshold (location) parameter, theta. The size of R is the common size of the input arguments if all are arrays. If any parameter is a scalar, the size of R is the size of the other parameters.

R = gprnd(K, sigma, theta, m, n, ...) or R = gprnd(K, sigma, theta, [m, n, ...]) generates an m-by-n-by-... array. The K, sigma, theta parameters can each be scalars or arrays of the same size as R.

When K = 0 and theta = 0, the GP is equivalent to the exponential distribution. When K > 0 and theta = sigma/K, the GP is equivalent to the Pareto distribution. The mean of the GP is not finite when K ≥ 1, and the variance is not finite when K ≥ 1/2. When K ≥ 0, the GP has positive density for

X > theta, or, when

$$0 \leq \frac{X - \theta}{\sigma} \leq -\frac{1}{K}$$

References [1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also random | gppdf | gpcdf | gpinv | gpstat | gpfit | gplike

Purpose Generalized Pareto mean and variance

Syntax `[M,V] = gpstat(K,sigma,theta)`

Description `[M,V] = gpstat(K,sigma,theta)` returns the mean of and variance for the generalized Pareto (GP) distribution with the tail index (shape) parameter `K`, scale parameter `sigma`, and threshold (location) parameter, `theta`.

The default value for `theta` is 0.

When `K = 0` and `theta = 0`, the GP is equivalent to the exponential distribution. When `K > 0` and `theta = sigma/K`, the GP is equivalent to the Pareto distribution. The mean of the GP is not finite when $K \geq 1$, and the variance is not finite when $K \geq 1/2$. When $K \geq 0$, the GP has positive density for $X > \theta$, or when

$$K < 0, 0 \leq \frac{X - \theta}{\sigma} \leq -\frac{1}{K}.$$

References

[1] Embrechts, P., C. Klüppelberg, and T. Mikosch. *Modelling Extremal Events for Insurance and Finance*. New York: Springer, 1997.

[2] Kotz, S., and S. Nadarajah. *Extreme Value Distributions: Theory and Applications*. London: Imperial College Press, 2000.

See Also

`gppdf` | `gpcdf` | `gpinv` | `gpfit` | `gplike` | `gprnd`

TreeBagger.growTrees

Purpose Train additional trees and add to ensemble

Syntax
B = growTrees(B,ntrees)
B = growTrees(B,ntrees,'param1',val1,'param2',val2,...)

Description B = growTrees(B,ntrees) grows ntrees new trees and appends them to those trees already stored in the ensemble B.

B = growTrees(B,ntrees,'param1',val1,'param2',val2,...)
pecifies optional parameter name/value pairs:

'nprint' Specifies that a diagnostic message showing training progress should display after every value training cycles (grown trees). Default is no diagnostic messages.

'options' A struct that specifies options that govern computation when growing the ensemble of decision trees. One option requests that the computation of decision trees on multiple bootstrap replicates uses multiple processors, if the Parallel Computing Toolbox is available. Two options specify the random number streams to use in selecting bootstrap replicates. You can create this argument with a call to `statset`. You can retrieve values of the individual fields with a call to `statget`. Applicable `statset` parameters are:

- 'UseParallel' — If 'always' and if a `matlabpool` of the Parallel Computing Toolbox is open, compute decision trees drawn on separate bootstrap replicates in parallel. If the Parallel Computing Toolbox is not installed, or a `matlabpool` is not open, computation occurs in serial mode. Default is 'never', or serial computation.

- **UseSubstreams** — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set **Streams** to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'.
- **Streams** — A **RandStream** object or cell array of such objects. If you do not specify **Streams**, **growTrees** uses the default stream or streams. If you choose to specify **Streams**, use a single object except in the case
 - You have an open MATLAB pool
 - **UseParallel** is 'always'
 - **UseSubstreams** is 'never'In that case, use a cell array the same size as the MATLAB pool.

See Also `classregtree`

grp2idx

Purpose Create index vector from grouping variable

Syntax `[G,GN]=grp2idx(S)`
`[G,GN,GL] = grp2idx(S)`

Description `[G,GN]=grp2idx(S)` creates an index vector `G` from the grouping variable `S`. `S` can be a categorical, numeric, or logical vector; a cell vector of strings; or a character matrix with each row representing a group label. The result `G` is a vector taking integer values from 1 up to the number `K` of distinct groups. `GN` is a cell array of strings representing group labels. `GN(G)` reproduces `S` (aside from any differences in type).

The order of `GN` depends on the grouping variable:

- For numeric and logical grouping variables, the order is the sorted order of `S`.
- For categorical grouping variables, the order is the order of `getlabels(S)`.
- For string grouping variables, the order is the order of first appearance in `S`.

`[G,GN,GL] = grp2idx(S)` returns a column vector `GL` representing the group levels. The set of groups and their order in `GL` and `GN` are the same, except that `GL` has the same type as `S`. If `S` is a character matrix, `GL(G,:)` reproduces `S`, otherwise `GL(G)` reproduces `S`.

`grp2idx` treats NaNs (numeric or logical), empty strings (char or cell array of strings), or `<undefined>` values (categorical) in `S` as missing values and returns NaNs in the corresponding rows of `G`. `GN` and `GL` don't include entries for missing values.

Examples Load the data in `hospital.mat` and create a categorical grouping variable:

```
load hospital
edges = 0:10:100;
labels = strcat(num2str((0:10:90)', '%d'), {'s'});
AgeGroup = ordinal(hospital.Age, labels, [], edges);
```



```
ages = hospital.Age(1:5)
ages =
    38
    43
    38
    40
    49

group = AgeGroup(1:5)
group =
    30s
    40s
    30s
    40s
    40s

indices = grp2idx(group)
indices =
    4
    5
    4
    5
    5
```

See Also

[gscatter](#) | [grpstats](#) | [crosstab](#) | [getlabels](#)

How To

- “Grouping Variables” on page 2-72

grpstats

Purpose Summary statistics organized by group

Syntax

```
stats = grpstats(ds,groupvar)
stats = grpstats(ds,groupvar,whichstats)
stats = grpstats(ds,groupvar,whichstats,Name,Value)

means = grpstats(X,group)
[stats1,...,statsN] = grpstats(X,group,whichstats)
[stats1,...,statsN] = grpstats(X,group,whichstats,'Alpha',
    alpha)

grpstats(X,group,alpha)
```

Description `stats = grpstats(ds,groupvar)` returns a dataset array with the means for the data groups in the dataset array `ds` determined by the values of the grouping variable or variables specified in `groupvar`.

- If there is a single grouping variable, then there is a row in `stats` for each value of the grouping variable. `grpstats` sorts the groups by order of appearance (if the grouping variable is a character array), in ascending numeric order (if the grouping variable is numeric), or in order of the levels (if the grouping variable is categorical).
- If `groupvar` is a cell array of strings containing multiple grouping variable names, or a vector of column numbers, then there is a row in `stats` for each observed unique combination of values of the grouping variables. `grpstats` sorts the groups by the values of the first grouping variable, then the second grouping variable, and so on.
- If any variables in `ds` (other than those specified in `groupvar`) are not numeric or logical arrays, then you must specify the names or column numbers of the numeric and logical variables for which you want to calculate means using the name-value pair argument, `DataVars`.

`stats = grpstats(ds,groupvar,whichstats)` returns the group values for the summary statistics types specified in `whichstats`.

`stats = grpstats(ds,groupvar,whichstats,Name,Value)` uses additional options specified by one or more `Name,Value` pair arguments.

`means = grpstats(X,group)` returns a column vector or matrix with the means of the groups of the data in the matrix or vector `X` determined by the values of the grouping variable or variables, `group`. The rows of `means` correspond to the grouping variable values.

- If there is a single grouping variable, then there is a row in `means` for each value of the grouping variable. `grpstats` sorts the groups by order of appearance (if the grouping variable is a character array), in ascending numeric order (if the grouping variable is numeric), or in order of the levels (if the grouping variable is categorical).
- If `group` is a cell array of grouping variables, then there is a row in `means` for each observed unique combination of values of the grouping variables. `grpstats` sorts the groups by the values of the first grouping variable, then the second grouping variable, and so on.
- If `X` is a matrix, then `means` is a matrix with the same number of columns as `X`. Each column of `means` has the group means for the corresponding column of `X`.

`[stats1,...,statsN] = grpstats(X,group,whichstats)` returns column vectors or arrays with group values for the summary statistic types specified in `whichstats`.

`[stats1,...,statsN] = grpstats(X,group,whichstats,'Alpha',alpha)` specifies the significance level for confidence and prediction intervals.

`grpstats(X,group,alpha)` plots the means of the groups of data in the vector or matrix `X` determined by the values of the grouping variable, `group`. The grouping variable values are on the horizontal plot axis. Each group mean has $100 \times (1 - \alpha)\%$ confidence intervals.

- If `X` is a matrix, then `grpstats` plots the means and confidence intervals for each column of `X`.
- If `group` is a cell array of grouping variables, then `grpstats` plots the means and confidence intervals for the groups of data in `X` determined by the unique combinations of values of the grouping variables. For example, if there are two grouping variables, each with two values, there are four possible combinations of grouping variable values. The plot includes only the combinations of values that exist in the input grouping variables (not all possible combinations).

Input Arguments

ds - Input data

dataset array

Input data, specified as a dataset array. The dataset array must include at least one variable that is a grouping variable.

Summary statistics can only be calculated for dataset array variables that have a numeric or logical data type. If any variables in `ds` (other than the grouping variables) are not numeric or logical arrays, then use the name-value pair argument `DataVars` to specify the names or column numbers of the numeric and logical variables for which to calculate summary statistics.

groupvar - Name or column of grouping variables

cell array of strings | vector of positive integers | logical vector | []

Name or column of the grouping variables in the input dataset array, `ds`, specified as a cell array of strings, vector of positive integers, or a logical vector. Use a string to specify a grouping variable name, a positive integer to specify a grouping variable column number, or logical values to indicate which variables are grouping variables (`true` for a grouping variable, `false` otherwise). Use a cell array of strings or a vector of positive integers to specify multiple grouping variables. Any variable specified in `groupvar` must be a categorical array, logical or numeric vector, or cell array of strings. Use `[]` to compute summary statistics for all data, without using groups.

For example, consider an input dataset array, `ds`, containing a variable named `Gender` in the fourth column. The data type of `Gender` might be a cell array of strings or a nominal array, with the unique values `Male` and `Female`. To specify `Gender` as the grouping variable, you can use either of these syntaxes:

- `stats = grpstats(ds, 'Gender')`
- `stats = grpstats(ds, 4)`

Data Types

double | logical | cell | char

whichstats - Types of summary statistics

string | function handle

Types of summary statistics to compute, specified as a string or function handle, or a cell array of strings and function handles. Use a cell array to specify multiple types of summary statistics.

Possible string values are:

'mean'	Mean
'sem'	Standard error of the mean
'numel'	Count, or number, of non-NaN elements
'gname'	Group name
'std'	Standard deviation
'var'	Variance
'min'	Minimum
'max'	Maximum
'range'	Range
'meanci'	95% confidence interval for the mean
'predci'	95% prediction interval for a new observation

Example: `[stat1,stat2] = grpstats(X,group,{'mean','sem'})`

You can specify different significance levels for the 'meanci' and 'predci' options using the name-value pair argument, Alpha.

To specify other types of summary statistics, you can use function handles. You can use the handle to any function that accepts a column or matrix of data, and returns the same size output each time `grpstats` calls it (even if the output for some groups is empty).

If the function accepts a column of data, then the function can return either a scalar value, or an *nvals*-by-1 column vector for descriptive statistics of length *nvals* (for example, confidence intervals have length two). If the function accepts a matrix, it must either return a 1-by-*ncols* row vector, or an *nvals*-by-*ncols* matrix, where *ncols* is the number of columns in the input data matrix.

Example: `[stat1,stat2,stat3] = grpstats(X,group,{'mean','std',@skewness})`

Data Types

char | function_handle

alpha - Significance level

scalar value in the range (0,1)

Significance level, specified as a scalar value in the range (0,1).

- When you specify 'meanci' or 'predci' in `whichstats`, you can use `alpha` to specify the significance level for the confidence or prediction intervals. If you specify `alpha`, then `grpstats` returns $100 \times (1 - \alpha)\%$ confidence or prediction intervals. If you do not specify `alpha`, then `grpstats` returns 95% intervals (`alpha = 0.05`).
- Use `alpha` with the `grpstats(X,group,alpha)` syntax to plot group means and corresponding $100 \times (1 - \alpha)\%$ confidence intervals.

Data Types

double

X - Input data

vector | matrix

Input data, specified as a vector or a matrix. If `X` is a matrix, then `grpstats` returns summary statistics for each column of `X`.

Data Types

double | single

group - Grouping variable

categorical array | logical or numeric vector | cell array of strings | []

Grouping variable, specified as a categorical array, logical or numeric vector, or cell array of strings. Each unique value in a grouping variable defines a group. `grpstats` groups data for summary statistics using the grouping variable values.

There must be a grouping variable value for each row of the input data `X`. Observations (rows) with the same value of the grouping variable are in the same group. Use [] to compute summary statistics for all data, without using groups.

For example, if `Gender` is a cell array of strings with values 'Male' and 'Female', you can use `Gender` as a grouping variable to summarize your data by gender.

You can also use more than one grouping variable to group data for summary statistics. In this case, specify a cell array of grouping variables.

For example, if `Smoker` is a logical vector with values 0 for nonsmokers and 1 for smokers, then specifying the cell array {`Gender`,`Smoker`} divides observations into four groups: Male Smoker, Male Nonsmoker, Female Smoker, and Female Nonsmoker. `grpstats` returns summary statistics only for the combinations of values that exist in the input grouping variables (not all possible combinations).

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`,`Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1`,`Value1`,...,`NameN`,`ValueN`.

Example: `'DataVars',[1,3,4],'Alpha',0.01` specifies that summary statistics be calculated for the 1st, 3rd, and 4th variables in a dataset array, with 99% confidence intervals.

Alpha - Significance level

0.05 (default) | scalar value in the range (0,1)

Significance level for confidence and prediction intervals, specified as the comma-separated pair consisting of `'Alpha'` and a scalar value in the range (0,1).

When you include `'meanci'` or `'predci'` in `whichstats`, you can use Alpha to specify the significance level for confidence or prediction intervals. If you specify the value α , then `grpstats` returns $100 \times (1 - \alpha)\%$ confidence or prediction intervals.

If you do not specify a value for Alpha, then `grpstats` returns 95% intervals ($\alpha = 0.5$).

Example: `'Alpha',0.1`

Data Types

double

DataVars - Variable names or columns

cell array of strings | vector of positive integers | logical vector

Variable names or columns indicating which variables in the input dataset array, `ds`, you want to compute summary statistics for, specified as a cell array of strings, vector of positive integers, or a logical vector. Use a string to specify a variable name, a positive integer to specify a variable column number, or logical values to indicate which variables to include (true if you want to compute summary statistics, false otherwise).

You must specify `DataVars` if there are any variables in `ds` (other than the grouping variables specified in `groupvar`) that are not numeric or logical arrays. Summary statistics can only be calculated for dataset array variables that have a numeric or logical data type.

Example: `'DataVars',{'Height','Weight'}`

Data Types

double | cell | char

VarNames - Variable names for output dataset array

cell array of strings

Variable names for output dataset array, `stats`, specified as a cell array of strings. By default, `grpstats` constructs output variable names by appending a prefix to the variable names from the input dataset array, `ds`. This prefix corresponds to the summary statistic name.

Example: `'VarNames', {'MaleMean', 'FemaleMean'}`

Data Types

cell

Output Arguments**stats - Group summary statistics**

dataset array

Group summary statistics, returned as a dataset array. `stats` contains summary statistic values for the groups of data in the dataset array `ds` determined by the levels of the grouping variables specified by `groupvar`. There is a row in `stats` for each observed value or combination of values in the variables specified by `groupvar`. The dataset array, `stats`, contains:

- All grouping variables specified by `groupvar`.
- The variable `GroupCount`, containing the number of observations in each group.
- Group summary statistic values for all variables in `ds` (other than those specified by `groupvar`), or for only the variables specified using `DataVars`.

The total number of variables in `stats` is $n_{groupvars} + 1 + n_{datavars} \times n_{stats}$, where $n_{groupvars}$ is the number of variables in `groupvar`, $n_{datavars}$ is the number of variables for which summary statistics are computed, and n_{stats} is the number of summary statistic types specified in `whichstats`.

`grpstats` assigns default names to the variables in `stats`, unless you specify variable names using the name-value pair argument `VarNames`.

means - Group means

column vector | array

Group means for the groups of data in the vector or matrix `X` determined by the levels of `group`, returned as an *ngroups*-by-*ncols* array. Here, *ngroups* is the number of unique values in the grouping variable, and *ncols* is the number of columns in `X`. If `X` is a vector, then `means` is a column vector.

stats1,...,statsN - Group summary statistics

column vectors | arrays

Group summary statistics for the groups of data in the vector or matrix `X` determined by the levels of `group`, returned as *ngroups*-by-*ncols* arrays. Here, *ngroups* is the number of unique values in the grouping variable, and *ncols* is the number of columns in `X`. You must specify an output argument for each type of summary statistic specified in `whichstats`.

If a summary statistic type in `whichstats` returns a value of length *nvals* (for example, a confidence interval is a descriptive statistic of length two), then the corresponding output argument is an *ngroups*-by-*ncols*-by-*nvals* array.

Examples

Dataset Array Summary Statistics Organized by Group

Load the sample data.

```
load('hospital')
```

The dataset array, `hospital`, has 100 observations and 7 variables.

Create a dataset array with only the variables `Sex`, `Age`, `Weight`, and `Smoker`.

```
ds = hospital(:,{'Sex','Age','Weight','Smoker'});
```

Sex is a nominal array, with levels Male and Female. The variables Age and Weight have numeric values, and Smoker has logical values.

Compute the mean for the numeric and logical arrays, Age, Weight, and Smoker, grouped by the levels in Sex.

```
stats = grpstats(ds, 'Sex')
```

```
stats =
```

	Sex	GroupCount	mean_Age	mean_Weight	mean_Smoker
Female	Female	53	37.717	130.47	0.24
Male	Male	47	38.915	180.53	0.44

stats is a dataset array with two rows, corresponding to the levels in Sex. GroupCount is the number of observations in each group. The means of Age, Weight, and Smoker, grouped by Sex, are given in mean_Age, mean_Weight, and mean_Smoker.

Compute the mean for Age and Weight, grouped by the values in Smoker.

```
stats = grpstats(ds, 'Smoker', 'mean', 'DataVars', {'Age', 'Weight'})
```

```
stats =
```

	Smoker	GroupCount	mean_Age	mean_Weight
0	false	66	37.97	149.91
1	true	34	38.882	161.94

In this case, not all variables in ds (excluding the grouping variable, Smoker) are numeric or logical arrays; the variable Sex is a nominal array. When not all variables in the input dataset array are numeric or logical arrays, you must specify the variables for which you want to calculate summary statistics using DataVars.

Compute the minimum and maximum weight, grouped by the combinations of values in Sex and Smoker.

```
stats = grpstats(ds, {'Sex', 'Smoker'}, {'min', 'max'}, ...
```

```
                                'DataVars', 'Weight')

stats =

      Sex      Smoker  GroupCount  min_Weight  max_Weight
Female_0  Female   false        40          111         147
Female_1  Female    true         13          115         146
Male_0    Male     false        26          158         194
Male_1    Male     true         21          164         202
```

There are two unique values in `Smoker` and two levels in `Sex`, for a total of four possible combinations of values: Female Nonsmoker (`Female_0`), Female Smoker (`Female_1`), Male Nonsmoker (`Male_0`), and Male Smoker (`Male_1`).

Summary Statistics for a Dataset Array Without Grouping

Load the sample data.

```
load('hospital')
```

The dataset array, `hospital`, has 100 observations and 7 variables.

Create a dataset array with only the variables `Age`, `Weight`, and `Smoker`.

```
ds = hospital(:, {'Age', 'Weight', 'Smoker'});
```

The variables `Age` and `Weight` have numeric values, and `Smoker` has logical values.

Compute the mean, minimum, and maximum for the numeric and logical arrays, `Age`, `Weight`, and `Smoker`, with no grouping.

```
stats = grpstats(ds, [], {'mean', 'min', 'max'})
```

```
stats =

      GroupCount  mean_Age  min_Age  max_Age  mean_Weight
All           100     38.28     25       50         154
```

```
      min_Weight  max_Weight  mean_Smoker  min_Smoker  ma
All      111      202      0.34      false      tr
```

The observation name All indicates that all observations in ds were used to compute the summary statistics.

Group Means for a Matrix Using One or More Grouping Variables

Load the sample data.

```
load('carsmall')
```

All variables are measured for 100 cars. Origin is the country of origin for each car (France, Germany, Italy, Japan, Sweden, or USA). Cylinders has three unique values, 4, 6, and 8, indicating the number of cylinders in each car.

Calculate the mean acceleration, grouped by country of origin.

```
means = grpstats(Acceleration,Origin)
```

```
means =
    18.0500
    16.3778
    15.5000
    15.8867
    16.6000
    14.4377
```

means is a 6-by-1 vector of mean accelerations, where each value corresponds to a country of origin.

Calculate the mean acceleration, grouped by both country of origin and number of cylinders.

grpstats

```
means = grpstats(Acceleration,{Origin,Cylinders})
```

```
means =
```

```
18.0500
16.3375
16.7000
15.5000
15.9143
15.5000
16.6000
17.0818
16.5267
11.6406
```

There are 18 possible combinations of grouping variable values because `Origin` has 6 unique values and `Cylinders` has 3 unique values. Only 10 of the possible combinations appear in the data, so `means` is a 10-by-1 vector of group means corresponding to the observed combinations of values.

Return the group names along with the mean acceleration for each group.

```
[means,grps] = grpstats(Acceleration,{Origin,Cylinders},...
                        {'mean','gname'})
```

```
means =
```

```
17.0818
16.5267
11.6406
18.0500
15.9143
15.5000
16.3375
16.7000
16.6000
```

```
15.5000
```

```
grps =
```

```
'USA'      '4'
'USA'      '6'
'USA'      '8'
'France'   '4'
'Japan'    '4'
'Japan'    '6'
'Germany'  '4'
'Germany'  '6'
'Sweden'   '4'
'Italy'    '4'
```

The output `grps` shows the 10 observed combinations of grouping variable values. For example, the mean acceleration of 4-cylinder cars made in France is 18.05.

Multiple Summary Statistics for a Matrix Organized by Group

Load the sample data.

```
load('carsmall')
```

The variable `Acceleration` was measured for 100 cars. The variable `Origin` is the country of origin for each car (France, Germany, Italy, Japan, Sweden, or USA).

Return the minimum, median, and maximum acceleration, grouped by country of origin.

```
[grpMin,grpMed,grpMax,grp] = grpstats(Acceleration,Origin,...
                                     {'min','median','max','gname'})
```

```
grpMin =
```

grpstats

8.0000
15.3000
13.9000
12.2000
15.7000
15.5000

grpMed =

14.7000
17.5000
15.7000
15.3000
16.6000
15.5000

grpMax =

22.2000
21.9000
18.2000
24.6000
17.5000
15.5000

grp =

'USA'
'France'
'Japan'
'Germany'
'Sweden'
'Italy'

The sample car with the lowest acceleration is made in the USA, and the sample car with the highest acceleration is made in Germany.

Plot Prediction Intervals for a New Observation in Each Group

Load the sample data.

```
load('carsmall')
```

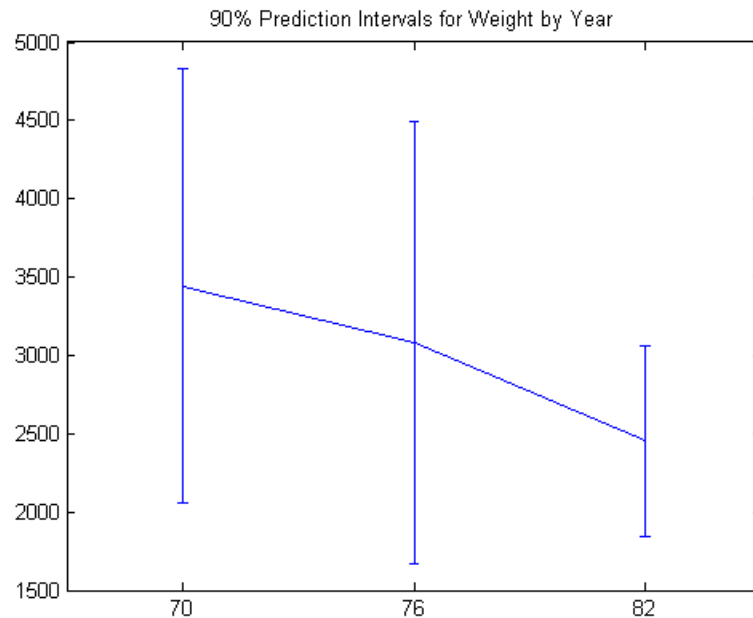
The variable `Weight` was measured for 100 cars. The variable `Model_Year` has three unique values, 70, 76, and 82, which correspond to model years 1970, 1976, and 1982.

Calculate the mean weight and 90% prediction intervals for each model year.

```
[means,pred,grp] = grpstats(Weight,Model_Year,...  
                            {'mean','predci','gname'},'Alpha',0.1);
```

Plot error bars showing the mean weight and 90% prediction intervals, grouped by model year. Label the horizontal axis with the group names.

```
ngrps = length(grp); % Number of groups  
  
figure()  
errorbar(1:ngrps)',means,pred(:,2)-means)  
set(gca,'xtick',1:ngrps,'xticklabel',grp)  
title('90% Prediction Intervals for Weight by Year')
```



Plot Group Means and Confidence Intervals

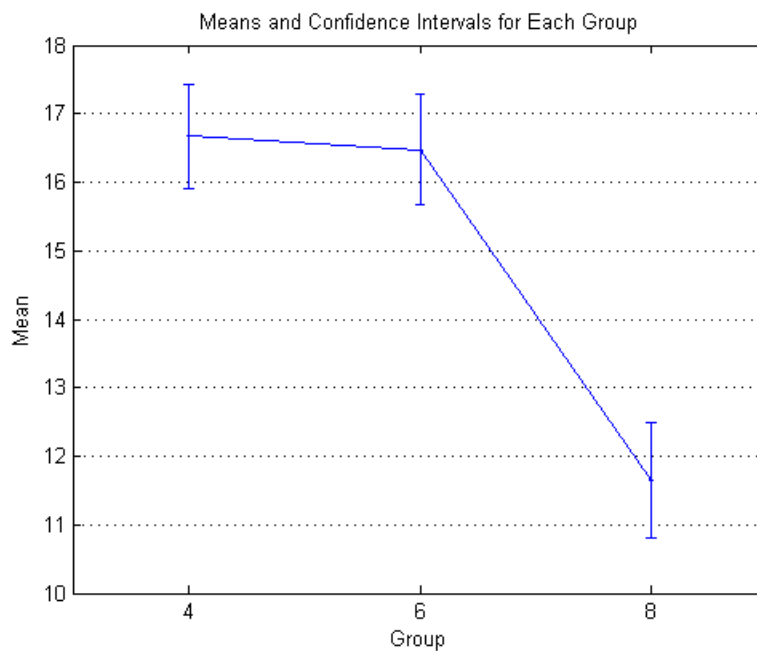
Load the sample data.

```
load('carsmall')
```

The variables `Acceleration` and `Weight` are the acceleration and weight values measured for 100 cars. The variable `Cylinders` is the number of cylinders in each car. The variable `Model_Year` has three unique values, 70, 76, and 82, which correspond to model years 1970, 1976, and 1982.

Plot mean acceleration, grouped by `Cylinders`, with 95% confidence intervals.

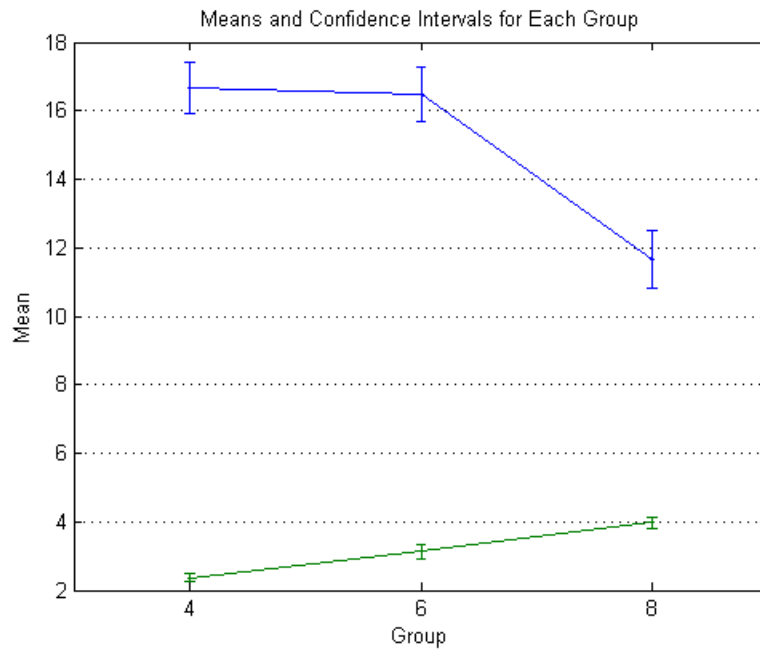
```
grpstats(Acceleration,Cylinders,0.05)
```



The mean acceleration for cars with 8 cylinders is significantly lower than for cars with 4 or 6 cylinders.

Plot mean acceleration and weight, grouped by `Cylinders`, and 95% confidence intervals. Scale the `Weight` values by 1000 so the means of `Weight` and `Acceleration` are the same order of magnitude.

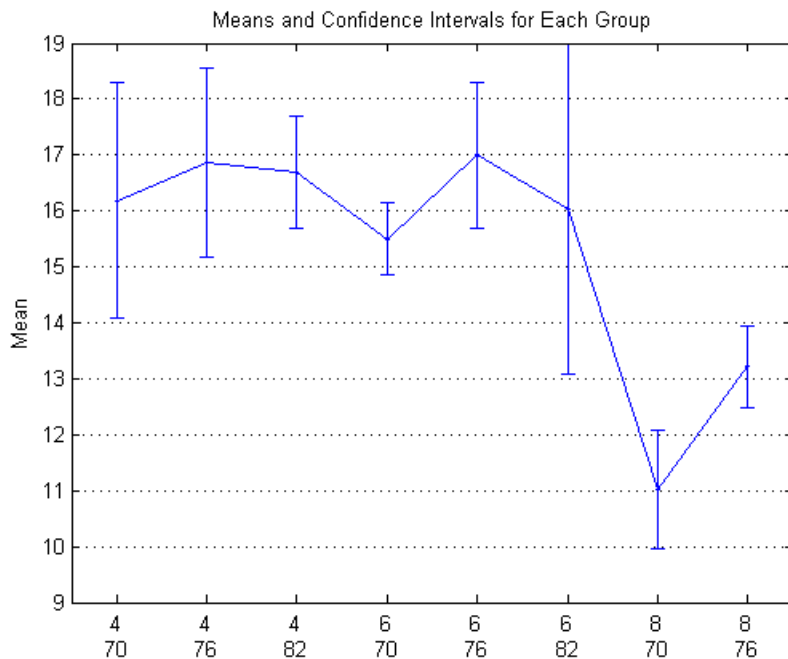
```
grpstats([Acceleration,Weight/1000],Cylinders,0.05)
```



The average weight of cars increases with the number of cylinders, and the average acceleration decreases with the number of cylinders.

Plot mean acceleration, grouped by both `Cylinders` and `Model_Year`. Specify 95% confidence intervals.

```
grpstats(Acceleration, {Cylinders, Model_Year}, 0.05)
```



There are nine possible combinations of grouping variable values because there are three unique values in `Cylinders` and three unique values in `Model_Year`. The plot does not show 8-cylinder cars with model year 1982 because the data did not include this combination.

The mean acceleration of 8-cylinder cars made in 1976 is significantly larger than the mean acceleration of 8-cylinder cars made in 1970.

Algorithms

- `grpstats` treats NaNs as missing values, and removes them from the input data before calculating summary statistics.
- `grpstats` ignores empty group names.

See Also `dataset` |

Related Examples

- “Summary Statistics Grouped by Category” on page 2-58
- “Test Differences Between Category Means” on page 2-49
- “Plot Data Grouped by Category” on page 2-45
- “Calculations on Dataset Arrays” on page 2-132

Concepts

- “Dataset Arrays” on page 2-156
- “Grouping Variables” on page 2-72
- “Categorical Arrays” on page 2-62

Purpose

Scatter plot by group

Syntax

```
gscatter(x,y,group)
gscatter(x,y,group,clr,sym,siz)
gscatter(x,y,group,clr,sym,siz,doleg)
gscatter(x,y,group,clr,sym,siz,doleg,xnam,ynam)
h = gscatter(...)
```

Description

`gscatter(x,y,group)` creates a scatter plot of `x` and `y`, grouped by `group`. `x` and `y` are vectors of the same size. `group` is a grouping variable in the form of a categorical variable, vector, string array, or cell array of strings. Alternatively, `group` can be a cell array containing several grouping variables (such as `{g1 g2 g3}`), in which case observations are in the same group if they have common values of all grouping variables. Points in the same group and appear on the graph with the same marker and color.

`gscatter(x,y,group,clr,sym,siz)` specifies the color, marker type, and size for each group. `clr` is a string array of colors recognized by the `plot` function. The default for `clr` is `'bgrcmyk'`. `sym` is a string array of symbols recognized by the `plot` command, with the default value `'.'`. `siz` is a vector of sizes, with the default determined by the `'DefaultLineMarkerSize'` property. If you do not specify enough values for all groups, `gscatter` cycles through the specified values as needed.

`gscatter(x,y,group,clr,sym,siz,doleg)` controls whether a legend is displayed on the graph (`doleg` is `'on'`, the default) or not (`doleg` is `'off'`).

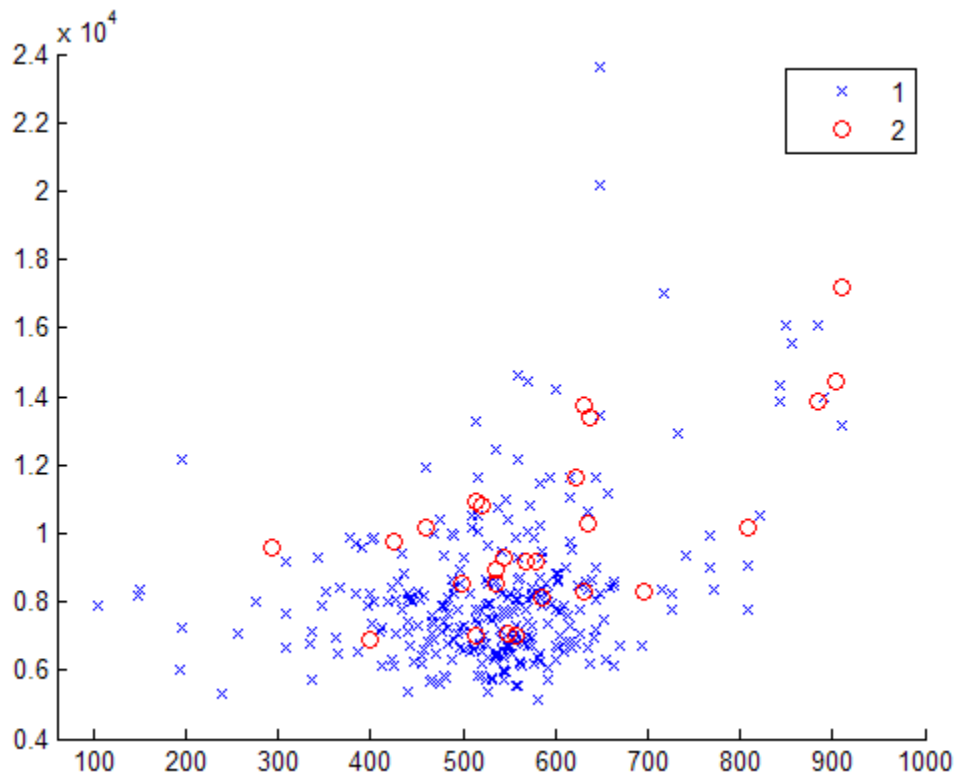
`gscatter(x,y,group,clr,sym,siz,doleg,xnam,ynam)` specifies the name to use for the `x`-axis and `y`-axis labels. If the `x` and `y` inputs are simple variable names and `xnam` and `ynam` are omitted, `gscatter` labels the axes with the variable names.

`h = gscatter(...)` returns an array of handles to the lines on the graph.

Examples

Load the cities data and look at the relationship between the ratings for climate (first column) and housing (second column) grouped by city size. We'll also specify the colors and plotting symbols.

```
load discrim  
gscatter(ratings(:,1),ratings(:,2),group,'br','xo')
```



See Also

[gplotmatrix](#) | [grpstats](#) | [scatter](#)

How To

- “Grouping Variables” on page 2-72

grandstream.gt

Purpose Greater than relation for handles

Syntax `h1 > h2`

Description `h1 > h2` performs element-wise comparisons between handle arrays `h1` and `h2`. `h1` and `h2` must be of the same dimensions unless one is a scalar. The result is a logical array of the same dimensions, where each element is an element-wise `>` result.

If one of `h1` or `h2` is scalar, scalar expansion is performed and the result will match the dimensions of the array that is not scalar.

`tf = gt(h1, h2)` stores the result in a logical array of the same dimensions.

See Also `grandstream | eq | ge | le | lt | ne`

Superclasses grandset

Purpose Halton quasi-random point sets

Description haltonset is a quasi-random point set class that produces points from the Halton sequence.

Construction haltonset Construct Halton quasi-random point set

Methods

Inherited Methods

Methods in the following table are inherited from grandset.

disp	Display grandset object
end	Last index in indexing expression for point set
length	Length of point set
ndims	Number of dimensions in matrix
net	Generate quasi-random point set
scramble	Scramble quasi-random point set
size	Number of dimensions in matrix
subsref	Subscripted reference for grandset

Properties

Inherited Properties

Properties in the following table are inherited from grandset.

Dimensions	Number of dimensions
Leap	Interval between points

haltonset

ScrambleMethod	Settings that control scrambling
Skip	Number of initial points to omit from sequence
Type	Name of sequence on which point set P is based

Copy Semantics

Handle. To learn how this affects your use of the class, see Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation.

References

[1] Kocis, L., and W. J. Whiten, "Computational Investigations of Low-Discrepancy Sequences," ACM Transactions on Mathematical Software, Vol. 23, No. 2, pp. 266-294, 1997.

See Also

sobolset

How To

- “Quasi-Random Point Sets” on page 6-16

Purpose

Construct Halton quasi-random point set

Syntax

```
p = haltonset(d)
p = haltonset(d,prop1,val1,prop2,val2,...)
```

Description

`p = haltonset(d)` constructs a d -dimensional point set `p` of the `haltonset` class, with default property settings.

`p = haltonset(d,prop1,val1,prop2,val2,...)` specifies property name/value pairs used to construct `p`.

The object `p` returned by `haltonset` encapsulates properties of a specified quasi-random sequence. The point set is finite, with a length determined by the `Skip` and `Leap` properties and by limits on the size of point set indices (maximum value of 2^{53}). Values of the point set are not generated and stored in memory until you access `p` using `net` or parenthesis indexing.

Examples

Generate a 3-D Halton point set, skip the first 1000 values, and then retain every 101st point:

```
p = haltonset(3,'Skip',1e3,'Leap',1e2)
p =
    Halton point set in 3 dimensions (8.918019e+013 points)
    Properties:
        Skip : 1000
        Leap : 100
        ScrambleMethod : none
```

Use `scramble` to apply reverse-radix scrambling:

```
p = scramble(p,'RR2')
p =
    Halton point set in 3 dimensions (8.918019e+013 points)
    Properties:
        Skip : 1000
        Leap : 100
        ScrambleMethod : RR2
```

Use `net` to generate the first four points:

```
X0 = net(p,4)
X0 =
    0.0928    0.6950    0.0029
    0.6958    0.2958    0.8269
    0.3013    0.6497    0.4141
    0.9087    0.7883    0.2166
```

Use parenthesis indexing to generate every third point, up to the 11th point:

```
X = p(1:3:11,:)
X =
    0.0928    0.6950    0.0029
    0.9087    0.7883    0.2166
    0.3843    0.9840    0.9878
    0.6831    0.7357    0.7923
```

References

[1] Kocis, L., and W. J. Whiten. “Computational Investigations of Low-Discrepancy Sequences.” *ACM Transactions on Mathematical Software*. Vol. 23, No. 2, 1997, pp. 266–294.

See Also

`net` | `scramble` | `sobolset`

Purpose Harmonic mean

Syntax `m = harmmean(X)`
`harmmean(X,dim)`

Description `m = harmmean(X)` calculates the harmonic mean of a sample. For vectors, `harmmean(x)` is the harmonic mean of the elements in `x`. For matrices, `harmmean(X)` is a row vector containing the harmonic means of each column. For N -dimensional arrays, `harmmean` operates along the first nonsingleton dimension of `X`.

`harmmean(X,dim)` takes the harmonic mean along dimension `dim` of `X`.

The harmonic mean is

$$m = \frac{n}{\sum_{i=1}^n \frac{1}{x_i}}$$

Examples The arithmetic mean is greater than or equal to the harmonic mean.

```
x = exprnd(1,10,6);

harmonic = harmmean(x)
harmonic =
    0.3382    0.3200    0.3710    0.0540    0.4936    0.0907

average = mean(x)
average =
    1.3509    1.1583    0.9741    0.5319    1.0088    0.8122
```

See Also `mean` | `median` | `geomean` | `trimmean`

hist3

Purpose Bivariate histogram

Syntax

```
hist3(X)
hist3(X,nbins)
hist3(X,ctrs)
hist3(X,'Edges',edges)
N = hist3(X,...)
[N,C] = hist3(X,...)
hist3(...,param1,val1,param2,val2,...)
```

Description `hist3(X)` bins the elements of the m -by-2 matrix X into a 10-by-10 grid of equally spaced containers, and plots a histogram. Each column of X corresponds to one dimension in the bin grid.

`hist3(X,nbins)` plots a histogram using an `nbins(1)`-by-`nbins(2)` grid of bins. `hist3(X,'Nbins',nbins)` is equivalent to `hist3(X,nbins)`.

`hist3(X,ctrs)`, where `ctrs` is a two-element cell array of numeric vectors with monotonically non-decreasing values, uses a 2-D grid of bins centered on `ctrs{1}` in the first dimension and on `ctrs{2}` in the second. `hist3` assigns rows of X falling outside the range of that grid to the bins along the outer edges of the grid, and ignores rows of X containing NaNs. `hist3(X,'Ctrs',ctrs)` is equivalent to `hist3(X,ctrs)`.

`hist3(X,'Edges',edges)`, where `edges` is a two-element cell array of numeric vectors with monotonically non-decreasing values, uses a 2-D grid of bins with edges at `edges{1}` in the first dimension and at `edges{2}` in the second. The (i,j) th bin includes the value $X(k,:)$ if

$$\begin{aligned} \text{edges}\{1\}(i) &\leq X(k,1) < \text{edges}\{1\}(i+1) \\ \text{edges}\{2\}(j) &\leq X(k,2) < \text{edges}\{2\}(j+1) \end{aligned}$$

Rows of X that fall on the upper edges of the grid, `edges{1}(end)` or `edges{2}(end)`, are counted in the (I,j) th or (i,J) th bins, where I and J are the lengths of `edges{1}` and `edges{2}`. `hist3` does not count rows of X falling outside the range of the grid. Use `-Inf` and `Inf` in `edges` to include all non-NaN values.

`N = hist3(X, ...)` returns a matrix containing the number of elements of `X` that fall in each bin of the grid, and does not plot the histogram.

`[N,C] = hist3(X, ...)` returns the positions of the bin centers in a 1-by-2 cell array of numeric vectors, and does not plot the histogram. `hist3(ax,X, ...)` plots onto an axes with handle `ax` instead of the current axes. See the axes reference page for more information about handles to plots.

`hist3(...,param1,val1,param2,val2,...)` allows you to specify graphics parameter name/value pairs to fine-tune the plot.

Examples

Example 1

Make a 3-D figure using a histogram with a density plot underneath:

```
load seamount
dat = [-y,x]; % Grid corrected for negative y-values
hold on
hist3(dat) % Draw histogram in 2D
```

```
n = hist3(dat); % Extract histogram data;
                % default to 10x10 bins
n1 = n';
n1( size(n,1) + 1 ,size(n,2) + 1 ) = 0;
```

Generate grid for 2-D projected view of intensities:

```
xb = linspace(min(dat(:,1)),max(dat(:,1)),size(n,1)+1);
yb = linspace(min(dat(:,2)),max(dat(:,2)),size(n,1)+1);
```

Make a pseudocolor plot:

```
h = pcolor(xb,yb,n1);
```

Set the z-level and colormap of the displayed grid:

```
set(h, 'zdata', ones(size(n1)) * -max(max(n)))
colormap(hot) % heat map
title('Seamount: ...
```

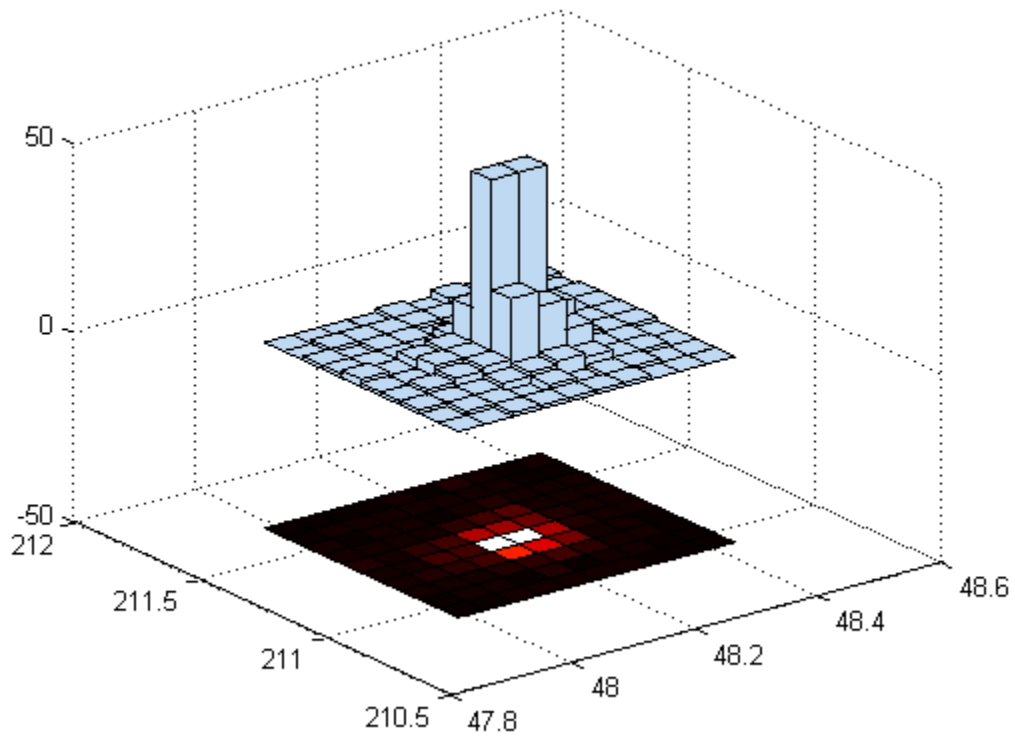
hist3

```
    Data Point Density Histogram and Intensity Map');  
grid on
```

Display the default 3-D perspective view:

```
view(3);
```

Seamount: Data Point Density Histogram and Intensity Map



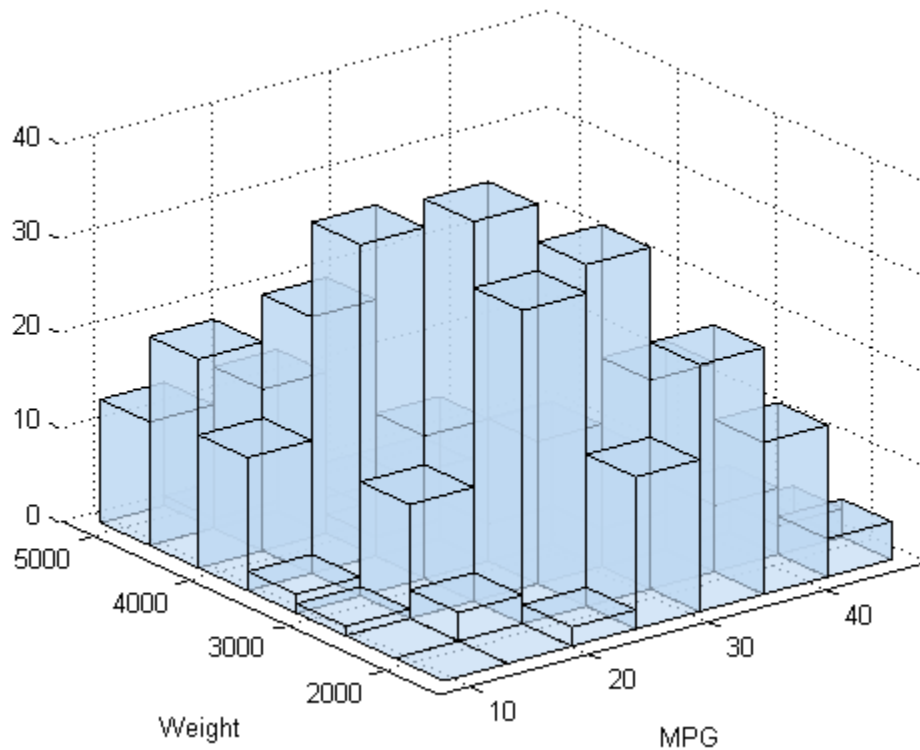
Example 2

Use the car data to make a histogram on a 7-by-7 grid of bins.

```
load carbig
X = [MPG,Weight];
hist3(X,[7 7]);
xlabel('MPG'); ylabel('Weight');
```

Make a histogram with semi-transparent bars:

```
hist3(X,[7 7],'FaceAlpha',.65);
xlabel('MPG'); ylabel('Weight');
set(gcf,'renderer','opengl');
```



hist3

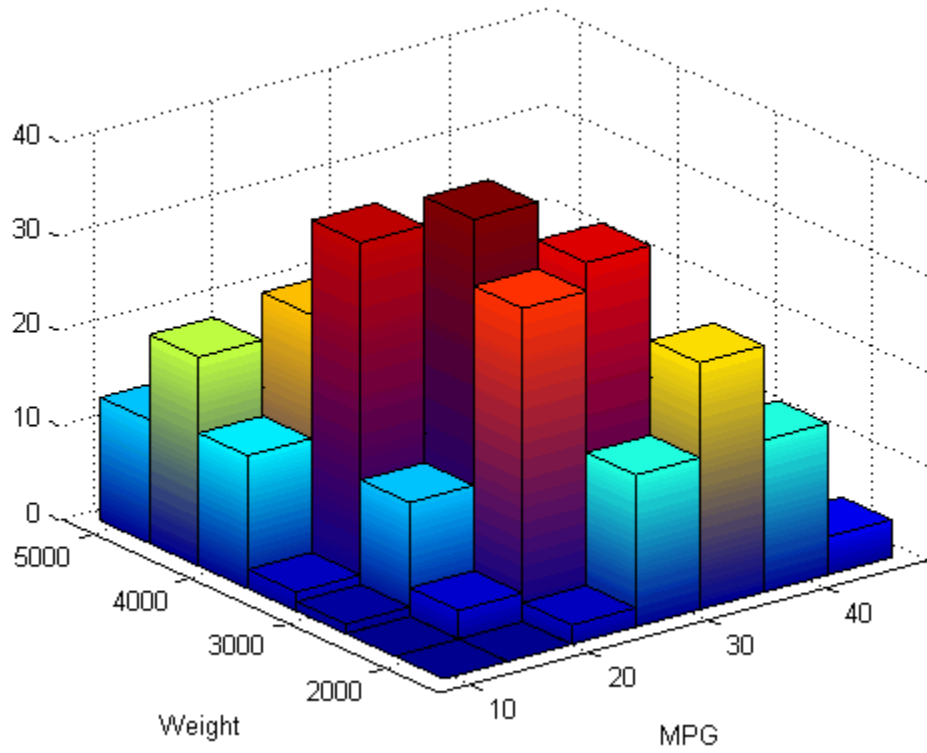
Specify bin centers, different in each direction; get back counts, but don't make the plot.

```
cnt = hist3(X, {0:10:50 2000:500:5000});
```

Example 3

Make a histogram with bars colored according to height.

```
load carbig
X = [MPG,Weight];
hist3(X,[7 7]);
xlabel('MPG'); ylabel('Weight');
set(gcf,'renderer','opengl');
set(get(gca,'child'),'FaceColor','interp','CDataMode',...
'auto');
```



See Also

`accumarray` | `bar` | `bar3` | `hist` | `histc`

categorical.hist

Purpose Plot histogram of categorical data

Syntax

```
hist(Y)
hist(Y,X)
hist(ax,...)
N = hist(...)
[N,X] = hist(...)
```

Description

`hist(Y)` plots a histogram bar plot of the counts for each level of the categorical vector `Y`. If `Y` is an m -by- n categorical matrix, `hist` computes counts for each column of `Y`, and plots a group of n bars for each categorical level.

`hist(Y,X)` plots bars only for the levels specified in `X`. `X` is a categorical vector or a cell array of level names as strings.

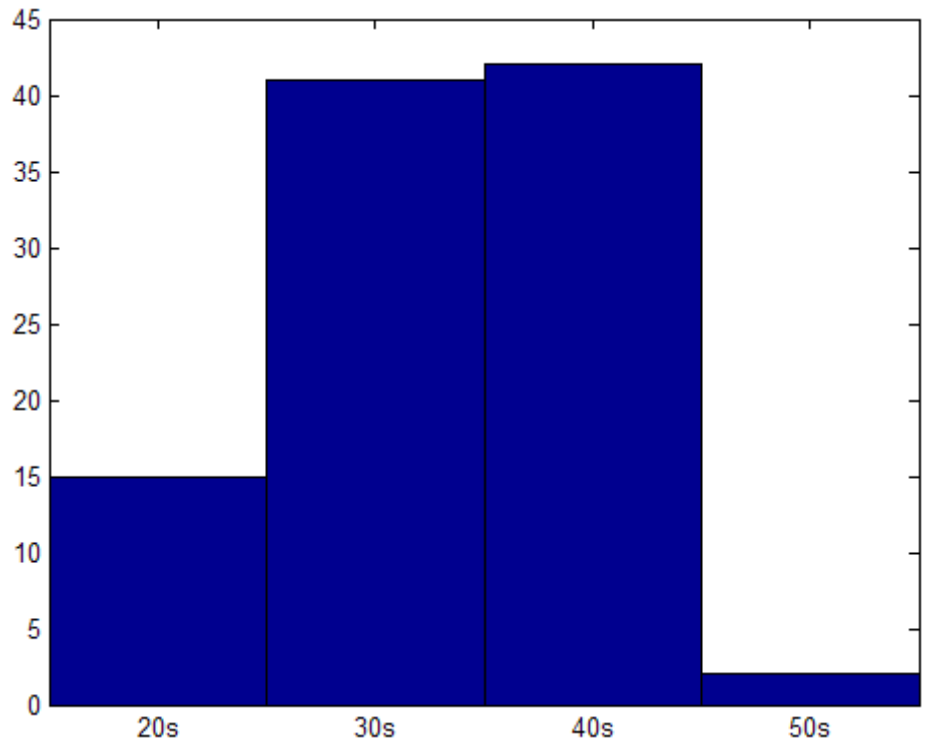
`hist(ax,...)` plots into the axes with handle `ax` instead of `gca`.

`N = hist(...)` returns the counts for each categorical level. If `Y` is a matrix, `hist` works down the columns of `Y` and returns a matrix of counts with one column for each column of `Y` and one row for each categorical level.

`[N,X] = hist(...)` returns the categorical levels corresponding to each count in `N`, or corresponding to each column of `N` if `Y` is a matrix.

Examples Create a histogram of age groups from the `hospital.mat` dataset:

```
load hospital
edges = 0:10:100;
labels = strcat(num2str((0:10:90)', '%d'), {'s'});
AgeGroup = ordinal(hospital.Age, labels, [], edges);
AgeGroup = droplevels(AgeGroup);
hist(AgeGroup)
```



See Also

`hist` | `categorical.levelcounts` | `categorical.getlevels`

histfit

Purpose Histogram with a distribution fit

Syntax

```
histfit(data)
histfit(data,nbins)
histfit(data,nbins,dist)

h = histfit( __ )
```

Description `histfit(data)` plots a histogram of values in `data` using the number of bins equal to the square root of the number of elements in `data` and fits a normal density function.

`histfit(data,nbins)` plots a histogram using `nbins` bins and fits a normal density function.

`histfit(data,nbins,dist)` plots a histogram with `nbins` bins and fits a density function from the distribution specified by `dist`.

`h = histfit(__)` returns a vector of handles `h`, where `h(1)` is the handle to the histogram and `h(2)` is the handle to the density curve. It can include any of the input arguments in previous syntaxes.

Input Arguments

data - Input data

vector

Input data, specified as a vector.

Example: `data = [1.5 2.5 4.6 1.2 3.4]`

Example: `data = [1.5 2.5 4.6 1.2 3.4]'`

Data Types

double | single

nbins - Number of bins

positive integer | []

Number of bins for the histogram, specified as a positive integer. Default value is the square root of the number of elements in `data`, rounded up. Use `[]` for the default number of bins when fitting a distribution.

Example: `y = histfit(x,8)`

Example: `y = histfit(x,10,'gamma')`

Example: `y = histfit(x,[],'weibull')`

Data Types

double | single

dist - Distribution to fit

'normal' (default) | string

Distribution to fit to the histogram, specified as a string. The following table shows the supported distributions.

dist	Description
'beta'	Beta
'birnbaumsaunders'	Birnbaum-Saunders
'burr'	Burr Type XII
'exponential'	Exponential
'extreme value' or 'ev'	Extreme value
'gamma'	Gamma
'generalized extreme value' or 'gev'	Generalized extreme value
'generalized pareto' or 'gp'	Generalized Pareto (threshold 0)
'inversegaussian'	Inverse Gaussian
'logistic'	Logistic
'loglogistic'	Loglogistic
'lognormal'	Lognormal

histfit

dist	Description
'nakagami'	Nakagami
'negative binomial' or 'nbin'	Negative binomial
'normal'	Normal
'poisson'	Poisson
'rayleigh'	Rayleigh
'rician'	Rician
'tlocationscale'	t location-scale
'weibull' or 'wbl'	Weibull
'kernel'	Nonparametric kernel-smoothing distribution. The density is evaluated at 100 equally spaced points that cover the range of the data in data. It works best with continuously distributed samples.

Data Types

char

Output Arguments

h - Handles for the plot

Handles for the plot, returned as a vector, where h(1) is the handle to the histogram, and h(2) is the handle to the density curve.

Data Types

function_handle

Examples

Histogram with a Normal Distribution Fit

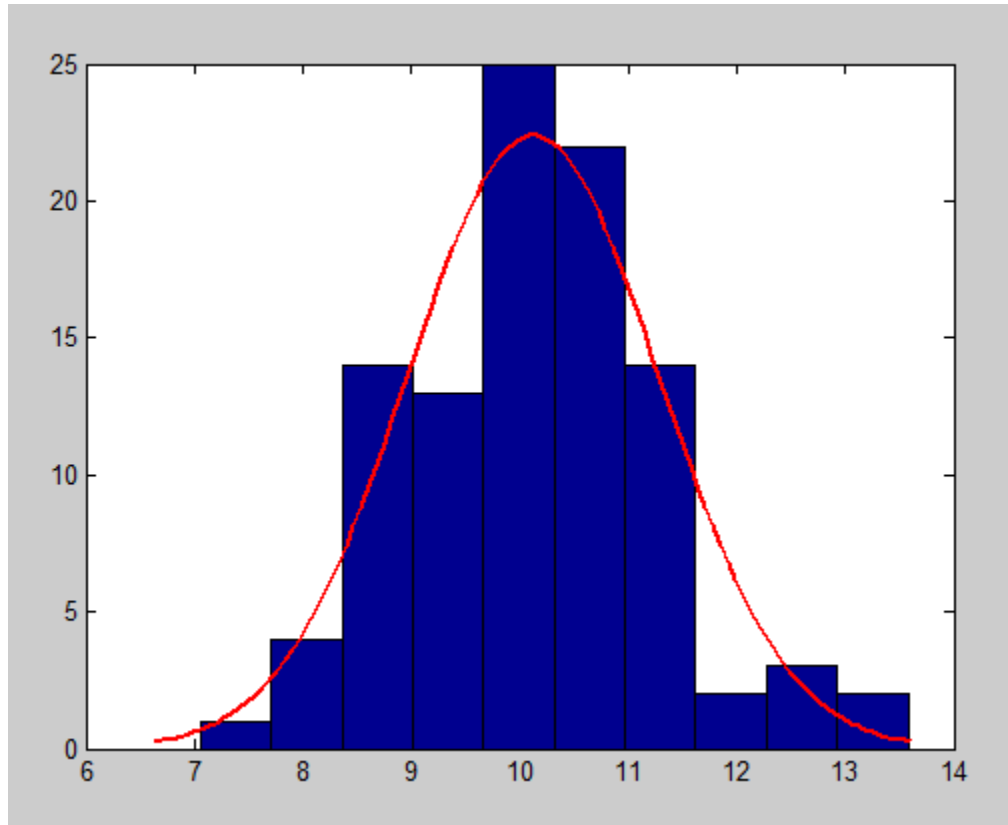
Generate a sample of size 100 from a normal distribution with mean 10 and variance 1.

```
rng('default'); % for reproducibility
```

```
r = normrnd(10,1,100,1);
```

Construct a histogram with a normal distribution fit.

```
histfit(r)
```



Histogram for a Given Number of Bins

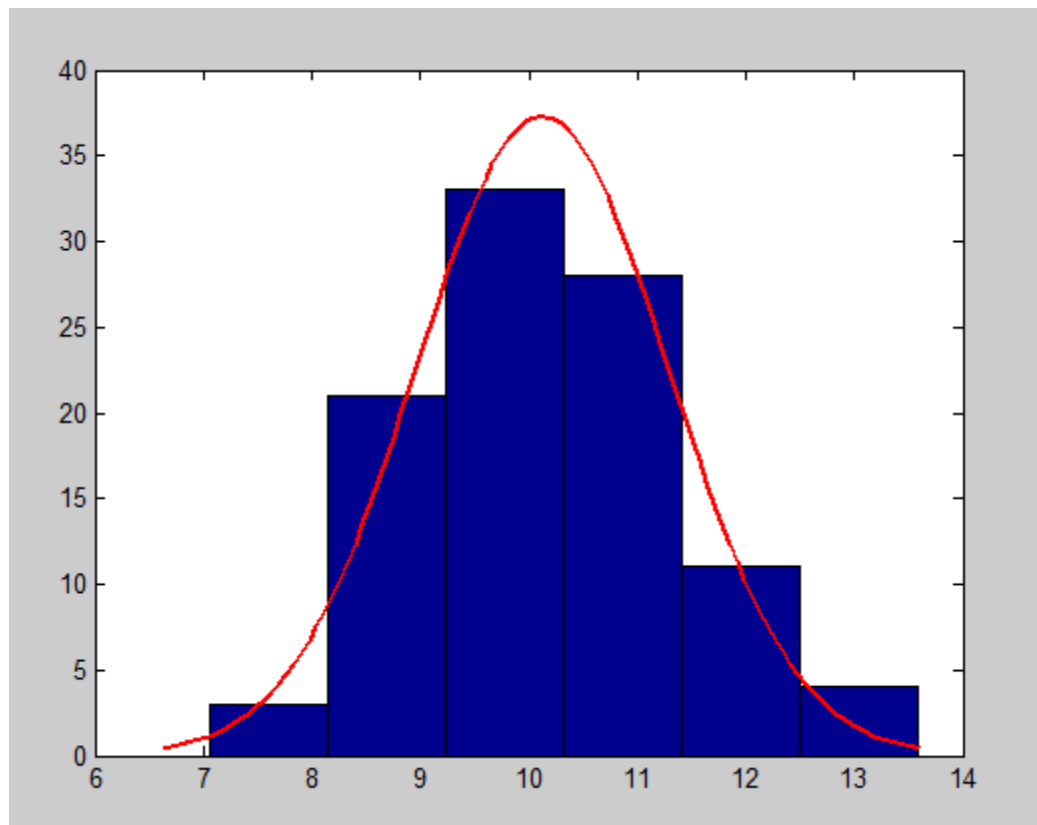
Generate a sample of size 100 from a normal distribution with mean 10 and variance 1.

histfit

```
rng('default'); % for reproducibility  
r = normrnd(10,1,100,1);
```

Construct a histogram using six bins with a normal distribution fit.

```
histfit(r,6)
```



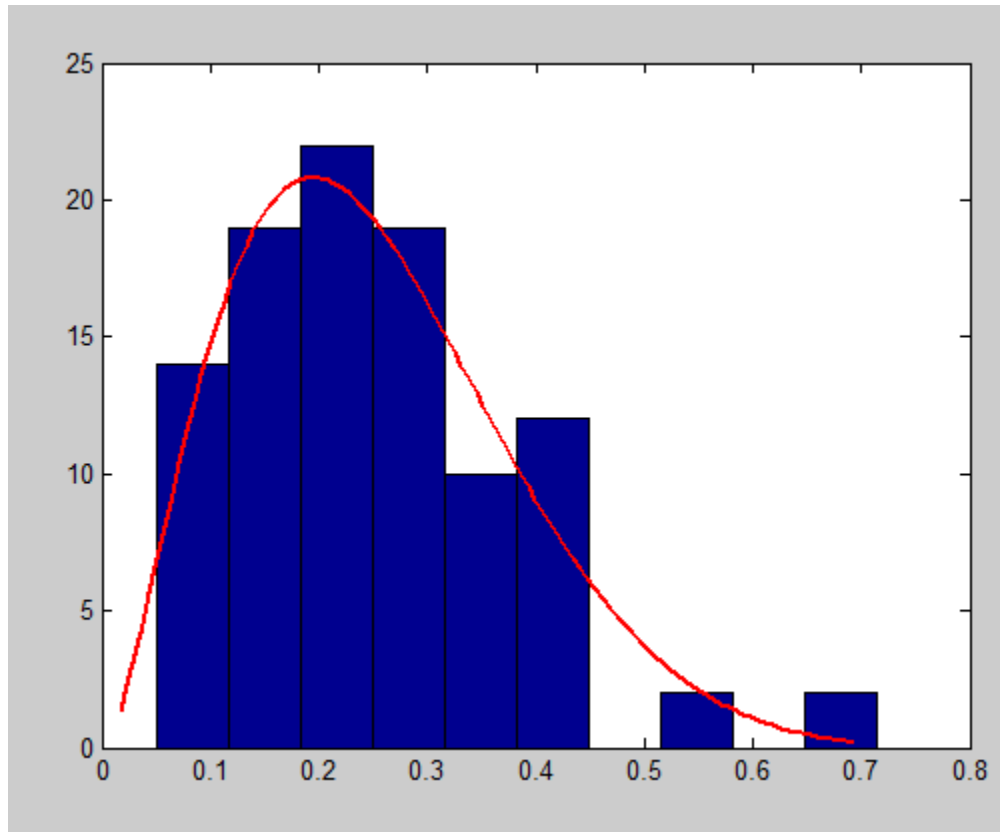
Histogram with a Specified Distribution Fit

Generate a sample of size 100 from a beta distribution with parameters (3,10).

```
rng('default') % for reproducibility  
b = betarnd(3,10,100,1);
```

Construct a histogram using 10 bins with a beta distribution fit.

```
histfit(b,10,'beta')
```



Histogram with a Kernel Smoothing Function Fit

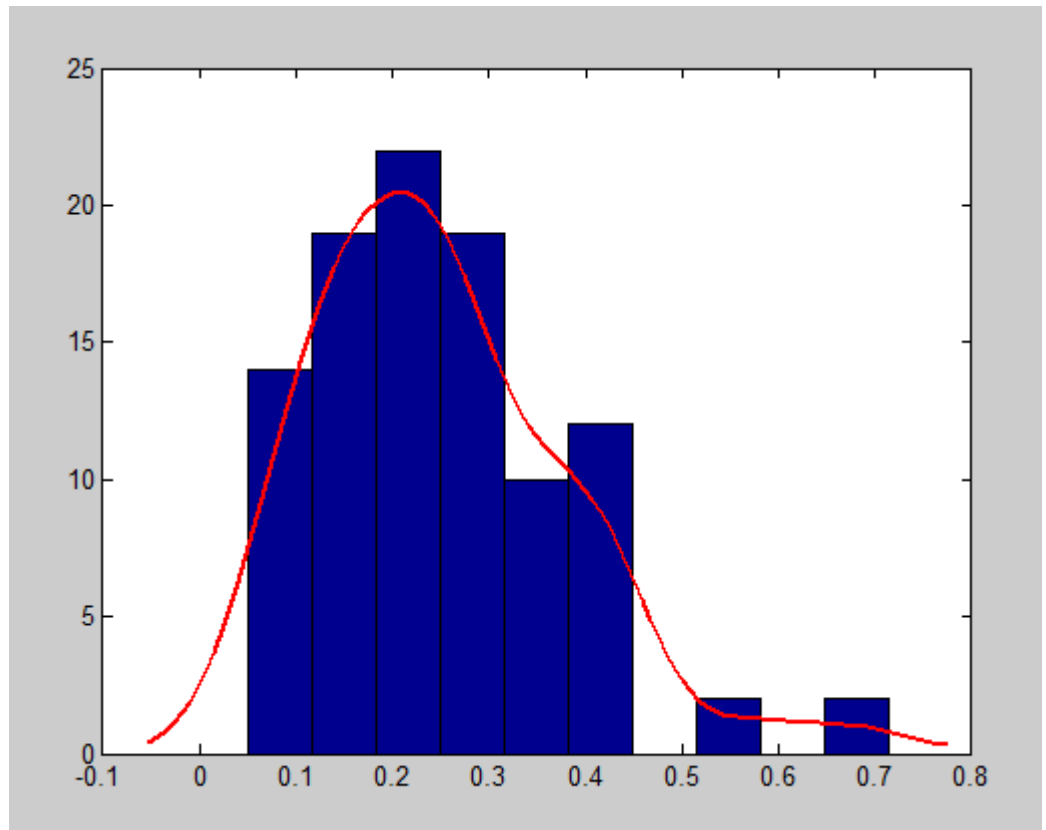
Generate a sample of size 100 from a beta distribution with parameters (3,10).

histfit

```
rng('default') % for reproducibility  
b = betarnd(3,10,[100,1]);
```

Construct a histogram using 10 bins with a smoothing function fit.

```
histfit(b,10,'kernel')
```



Handle for a Histogram with a Distribution Fit

Generate a sample of size 100 from a normal distribution with mean 10 and variance 1.

```
rng('default'); % for reproducibility  
r = normrnd(10,1,100,1);
```

Construct a histogram with a normal distribution fit.

```
h = histfit(r,10,'normal')
```

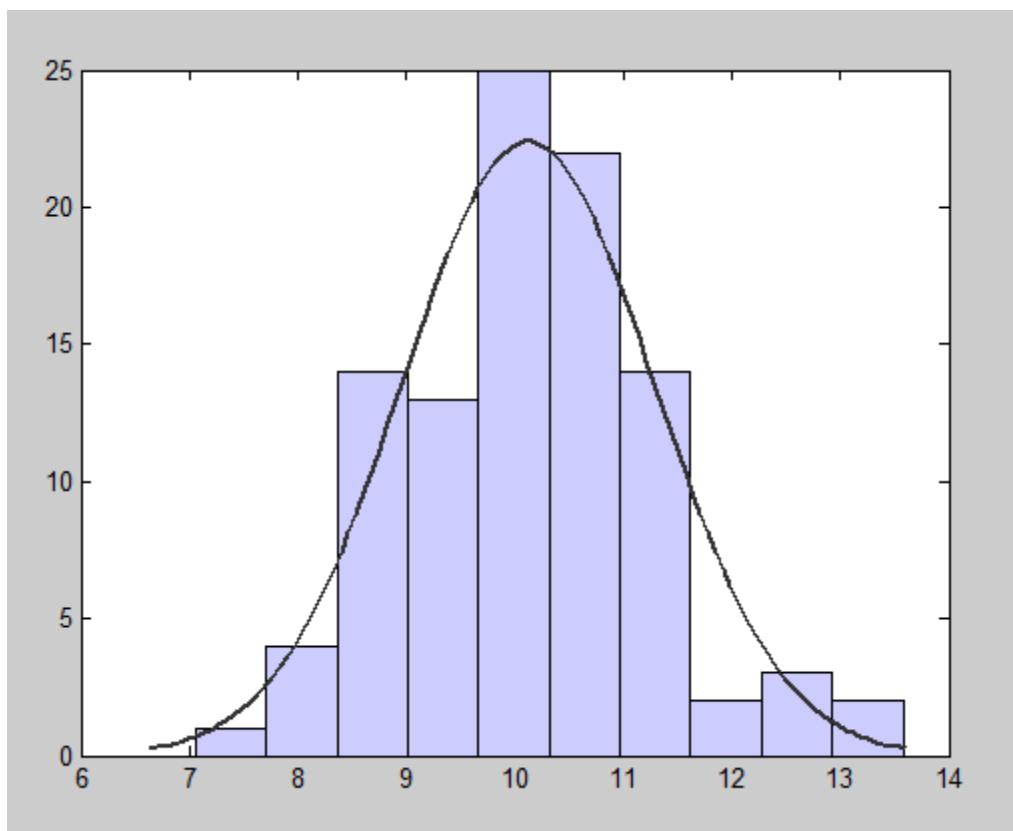
Change the bar colors of the histogram.

```
set(h(1),'FaceColor',[.8 .8 1])
```

Change the color of the density curve.

```
set(h(2),'Color',[.2 .2 .2])
```

histfit



See Also

`hist` | `normfit` | `dfittool`

Purpose

Hidden Markov model posterior state probabilities

Syntax

```
PSTATES = hmmdecode(seq,TRANS,EMIS)
[PSTATES,logpseq] = hmmdecode(...)
[PSTATES,logpseq,FORWARD,BACKWARD,S] = hmmdecode(...)
hmmdecode(...,'Symbols',SYMBOLS)
```

Description

PSTATES = hmmdecode(seq,TRANS,EMIS) calculates the posterior state probabilities, PSTATES, of the sequence seq, from a hidden Markov model. The posterior state probabilities are the conditional probabilities of being at state k at step i , given the observed sequence of symbols, sym. You specify the model by a transition probability matrix, TRANS, and an emissions probability matrix, EMIS. TRANS(i , j) is the probability of transition from state i to state j . EMIS(k , seq) is the probability that symbol seq is emitted from state k .

PSTATES is an array with the same length as seq and one row for each state in the model. The (i , j)th element of PSTATES gives the probability that the model is in state i at the j th step, given the sequence seq.

Note The function hmmdecode begins with the model in state 1 at step 0, prior to the first emission. hmmdecode computes the probabilities in PSTATES based on the fact that the model begins in state 1.

[PSTATES,logpseq] = hmmdecode(...) returns logpseq, the logarithm of the probability of sequence seq, given transition matrix TRANS and emission matrix EMIS.

[PSTATES,logpseq,FORWARD,BACKWARD,S] = hmmdecode(...) returns the forward and backward probabilities of the sequence scaled by S.

hmmdecode(...,'Symbols',SYMBOLS) specifies the symbols that are emitted. SYMBOLS can be a numeric array or a cell array of the names of the symbols. The default symbols are integers 1 through N, where N is the number of possible emissions.

hmmdecode

References

[1] Durbin, R., S. Eddy, A. Krogh, and G. Mitchison. *Biological Sequence Analysis*. Cambridge, UK: Cambridge University Press, 1998.

Examples

```
trans = [0.95,0.05;
         0.10,0.90];
emis = [1/6 1/6 1/6 1/6 1/6 1/6;
        1/10 1/10 1/10 1/10 1/10 1/2];

[seq,states] = hmmgenerate(100,trans,emis);
pStates = hmmdecode(seq,trans,emis);
[seq,states] = hmmgenerate(100,trans,emis,...
    'Symbols',{'one','two','three','four','five','six'})
pStates = hmmdecode(seq,trans,emis,...
    'Symbols',{'one','two','three','four','five','six'});
```

See Also

[hmmgenerate](#) | [hmmestimate](#) | [hmmviterbi](#) | [hmmtrain](#)

Purpose

Hidden Markov model parameter estimates from emissions and states

Syntax

```
[TRANS,EMIS] = hmmestimate(seq,states)
hmmestimate(...,'Symbols',SYMBOLS)
hmmestimate(...,'Statenames',STATENAMES)
hmmestimate(...,'Pseudoemissions',PSEUDOE)
hmmestimate(...,'Pseudotransitions',PSEUDOTR)
```

Description

`[TRANS,EMIS] = hmmestimate(seq,states)` calculates the maximum likelihood estimate of the transition, TRANS, and emission, EMIS, probabilities of a hidden Markov model for sequence, seq, with known states, states.

`hmmestimate(...,'Symbols',SYMBOLS)` specifies the symbols that are emitted. SYMBOLS can be a numeric array or a cell array of the names of the symbols. The default symbols are integers 1 through N, where N is the number of possible emissions.

`hmmestimate(...,'Statenames',STATENAMES)` specifies the names of the states. STATENAMES can be a numeric array or a cell array of the names of the states. The default state names are 1 through M, where M is the number of states.

`hmmestimate(...,'Pseudoemissions',PSEUDOE)` specifies pseudocount emission values in the matrix PSEUDO. Use this argument to avoid zero probability estimates for emissions with very low probability that might not be represented in the sample sequence. PSEUDOE should be a matrix of size m -by- n , where m is the number of states in the hidden Markov model and n is the number of possible emissions. If the $i \rightarrow k$ emission does not occur in seq, you can set PSEUDOE(i,k) to be a positive number representing an estimate of the expected number of such emissions in the sequence seq.

`hmmestimate(...,'Pseudotransitions',PSEUDOTR)` specifies pseudocount transition values. You can use this argument to avoid zero probability estimates for transitions with very low probability that might not be represented in the sample sequence. PSEUDOTR should be a matrix of size m -by- m , where m is the number of states in the hidden

Markov model. If the $i \rightarrow j$ transition does not occur in `states`, you can set `PSEUDOTR(i, j)` to be a positive number representing an estimate of the expected number of such transitions in the sequence `states`.

Pseudotransitions and Pseudoemissions

If the probability of a specific transition or emission is very low, the transition might never occur in the sequence `states`, or the emission might never occur in the sequence `seq`. In either case, the algorithm returns a probability of 0 for the given transition or emission in `TRANS` or `EMIS`. You can compensate for the absence of transition with the 'Pseudotransitions' and 'Pseudoemissions' arguments. The simplest way to do this is to set the corresponding entry of `PSEUDO` or `PSEUDOTR` to 1. For example, if the transition $i \rightarrow j$ does not occur in `states`, set `PSEUOTR(i, j) = 1`. This forces `TRANS(i, j)` to be positive.

If you have an estimate for the expected number of transitions $i \rightarrow j$ in a sequence of the same length as `states`, and the actual number of transitions $i \rightarrow j$ that occur in `seq` is substantially less than what you expect, you can set `PSEUOTR(i, j)` to the expected number. This increases the value of `TRANS(i, j)`. For transitions that do occur in `states` with the frequency you expect, set the corresponding entry of `PSEUDOTR` to 0, which does not increase the corresponding entry of `TRANS`.

If you do not know the sequence of states, use `hmmtrain` to estimate the model parameters.

References

[1] Durbin, R., S. Eddy, A. Krogh, and G. Mitchison. *Biological Sequence Analysis*. Cambridge, UK: Cambridge University Press, 1998.

Examples

```
trans = [0.95,0.05; 0.10,0.90];
emis = [1/6 1/6 1/6 1/6 1/6 1/6;
        1/10 1/10 1/10 1/10 1/10 1/2];

[seq,states] = hmmgenerate(1000,trans,emis);
[estimateTR,estimateE] = hmmestimate(seq,states);
```

See Also

`hmmgenerate` | `hmmdecode` | `hmmviterbi` | `hmmtrain`

hmmgenerate

Purpose Hidden Markov model states and emissions

Syntax `[seq,states] = hmmgenerate(len,TRANS,EMIS)`
`hmmgenerate(...,'Symbols',SYMBOLS)`
`hmmgenerate(...,'Statenames',STATENAMES)`

Description `[seq,states] = hmmgenerate(len,TRANS,EMIS)` takes a known Markov model, specified by transition probability matrix TRANS and emission probability matrix EMIS, and uses it to generate

- A random sequence `seq` of emission symbols
- A random sequence `states` of states

The length of both `seq` and `states` is `len`. `TRANS(i,j)` is the probability of transition from state `i` to state `j`. `EMIS(k,l)` is the probability that symbol `l` is emitted from state `k`.

Note The function `hmmgenerate` begins with the model in state 1 at step 0, prior to the first emission. The model then makes a transition to state i_1 , with probability T_{1i_1} , and generates an emission a_{k_1} with probability $E_{i_1k_1}$. `hmmgenerate` returns i_1 as the first entry of `states`, and a_{k_1} as the first entry of `seq`.

`hmmgenerate(...,'Symbols',SYMBOLS)` specifies the symbols that are emitted. `SYMBOLS` can be a numeric array or a cell array of the names of the symbols. The default symbols are integers 1 through N, where N is the number of possible emissions.

`hmmgenerate(...,'Statenames',STATENAMES)` specifies the names of the states. `STATENAMES` can be a numeric array or a cell array of the names of the states. The default state names are 1 through M, where M is the number of states.

Since the model always begins at state 1, whose transition probabilities are in the first row of TRANS, in the following example, the first entry of

the output states is be 1 with probability 0.95 and 2 with probability 0.05.

Examples

```
trans = [0.95,0.05;
         0.10,0.90];
emis = [1/6 1/6 1/6 1/6 1/6 1/6;
        1/10 1/10 1/10 1/10 1/10 1/2];

[seq,states] = hmmgenerate(100,trans,emis)
[seq,states] = hmmgenerate(100,trans,emis,...
    'Symbols',{'one','two','three','four','five','six'},...
    'Statenames',{'fair';'loaded'})
```

See Also

[hmmviterbi](#) | [hmmdecode](#) | [hmmestimate](#) | [hmmtrain](#)

hmmtrain

Purpose Hidden Markov model parameter estimates from emissions

Syntax

```
[ESTTR,ESTEMIT] = hmmtrain(seq,TRGUESS,EMITGUESS)
hmmtrain(...,'Algorithm',algorithm)
hmmtrain(...,'Symbols',SYMBOLS)
hmmtrain(...,'Tolerance',tol)
hmmtrain(...,'Maxiterations',maxiter)
hmmtrain(...,'Verbose',true)
hmmtrain(...,'Pseudoemissions',PSEUDOE)
hmmtrain(...,'Pseudotransitions',PSEUDOTR)
```

Description [ESTTR,ESTEMIT] = `hmmtrain(seq,TRGUESS,EMITGUESS)` estimates the transition and emission probabilities for a hidden Markov model using the Baum-Welch algorithm. `seq` can be a row vector containing a single sequence, a matrix with one row per sequence, or a cell array with each cell containing a sequence. `TRGUESS` and `EMITGUESS` are initial estimates of the transition and emission probability matrices. `TRGUESS(i,j)` is the estimated probability of transition from state `i` to state `j`. `EMITGUESS(i,k)` is the estimated probability that symbol `k` is emitted from state `i`.

`hmmtrain(...,'Algorithm',algorithm)` specifies the training algorithm. *algorithm* can be either 'BaumWelch' or 'Viterbi'. The default algorithm is 'BaumWelch'.

`hmmtrain(...,'Symbols',SYMBOLS)` specifies the symbols that are emitted. `SYMBOLS` can be a numeric array or a cell array of the names of the symbols. The default symbols are integers 1 through `N`, where `N` is the number of possible emissions.

`hmmtrain(...,'Tolerance',tol)` specifies the tolerance used for testing convergence of the iterative estimation process. The default tolerance is `1e-4`.

`hmmtrain(...,'Maxiterations',maxiter)` specifies the maximum number of iterations for the estimation process. The default maximum is 100.

`hmmtrain(..., 'Verbose', true)` returns the status of the algorithm at each iteration.

`hmmtrain(..., 'Pseudoemissions', PSEUDO_E)` specifies pseudocount emission values for the Viterbi training algorithm. Use this argument to avoid zero probability estimates for emissions with very low probability that might not be represented in the sample sequence. `PSEUDO_E` should be a matrix of size m -by- n , where m is the number of states in the hidden Markov model and n is the number of possible emissions. If the $i \rightarrow k$ emission does not occur in `seq`, you can set `PSEUDO_E(i, k)` to be a positive number representing an estimate of the expected number of such emissions in the sequence `seq`.

`hmmtrain(..., 'Pseudotransitions', PSEUDO_T)` specifies pseudocount transition values for the Viterbi training algorithm. Use this argument to avoid zero probability estimates for transitions with very low probability that might not be represented in the sample sequence. `PSEUDO_T` should be a matrix of size m -by- m , where m is the number of states in the hidden Markov model. If the $i \rightarrow j$ transition does not occur in `states`, you can set `PSEUDO_T(i, j)` to be a positive number representing an estimate of the expected number of such transitions in the sequence `states`.

If you know the states corresponding to the sequences, use `hmmestimate` to estimate the model parameters.

Tolerance

The input argument `'tolerance'` controls how many steps the `hmmtrain` algorithm executes before the function returns an answer. The algorithm terminates when all of the following three quantities are less than the value that you specify for `tolerance`:

- The log likelihood that the input sequence `seq` is generated by the currently estimated values of the transition and emission matrices
- The change in the norm of the transition matrix, normalized by the size of the matrix
- The change in the norm of the emission matrix, normalized by the size of the matrix

hmmtrain

The default value of 'tolerance' is .0001. Increasing the tolerance decreases the number of steps the hmmtrain algorithm executes before it terminates.

maxiterations

The maximum number of iterations, 'maxiterations', controls the maximum number of steps the algorithm executes before it terminates. If the algorithm executes maxiter iterations before reaching the specified tolerance, the algorithm terminates and the function returns a warning. If this occurs, you can increase the value of 'maxiterations' to make the algorithm reach the desired tolerance before terminating.

References

[1] Durbin, R., S. Eddy, A. Krogh, and G. Mitchison. *Biological Sequence Analysis*. Cambridge, UK: Cambridge University Press, 1998.

Examples

```
trans = [0.95,0.05;  
         0.10,0.90];  
emis = [1/6, 1/6, 1/6, 1/6, 1/6, 1/6;  
        1/10, 1/10, 1/10, 1/10, 1/10, 1/2];  
  
seq1 = hmmgenerate(100,trans,emis);  
seq2 = hmmgenerate(200,trans,emis);  
seqs = {seq1,seq2};  
[estTR,estE] = hmmtrain(seqs,trans,emis);
```

See Also

[hmmgenerate](#) | [hmmdecode](#) | [hmmestimate](#) | [hmmviterbi](#)

Purpose Hidden Markov model most probable state path

Syntax

```
STATES = hmmviterbi(seq,TRANS,EMIS)
hmmviterbi(...,'Symbols',SYMBOLS)
hmmviterbi(...,'Statenames',STATENAMES)
```

Description STATES = hmmviterbi(seq,TRANS,EMIS) given a sequence, seq, calculates the most likely path through the hidden Markov model specified by transition probability matrix, TRANS, and emission probability matrix EMIS. TRANS(i,j) is the probability of transition from state i to state j. EMIS(i,k) is the probability that symbol k is emitted from state i.

Note The function hmmviterbi begins with the model in state 1 at step 0, prior to the first emission. hmmviterbi computes the most likely path based on the fact that the model begins in state 1.

hmmviterbi(...,'Symbols',SYMBOLS) specifies the symbols that are emitted. SYMBOLS can be a numeric array or a cell array of the names of the symbols. The default symbols are integers 1 through N, where N is the number of possible emissions.

hmmviterbi(...,'Statenames',STATENAMES) specifies the names of the states. STATENAMES can be a numeric array or a cell array of the names of the states. The default state names are 1 through M, where M is the number of states.

Examples

```
trans = [0.95,0.05;
         0.10,0.90];
emis = [1/6 1/6 1/6 1/6 1/6 1/6;
        1/10 1/10 1/10 1/10 1/10 1/2];

[seq,states] = hmmgenerate(100,trans,emis);
estimatedStates = hmmviterbi(seq,trans,emis);
```

hmmviterbi

```
[seq,states] = ...
    hmmgenerate(100,trans,emis,...
        'Statenames',{'fair';'loaded'});
estimatesStates = ...
    hmmviterbi(seq,trans,emis,...
        'Statenames',{'fair';'loaded'});
```

References

[1] Durbin, R., S. Eddy, A. Krogh, and G. Mitchison. *Biological Sequence Analysis*. Cambridge, UK: Cambridge University Press, 1998.

See Also

[hmmgenerate](#) | [hmmdecode](#) | [hmmestimate](#) | [hmmtrain](#)

Purpose Horizontal concatenation for categorical arrays

Syntax `C = horzcat(dim,A,B,...)`
`C = horzcat(A,B)`

Description `C = horzcat(dim,A,B,...)` horizontally concatenates the categorical arrays `A,B,...`. For matrices, all inputs must have the same number of rows. For n-D arrays, all inputs must have the same sizes except in the second dimension. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs, as determined by their labels.

`C = horzcat(A,B)` is called for the syntax `[A B]`.

See Also `cat` | `vertcat`

dataset.horzcat

Purpose Horizontal concatenation for dataset arrays

Syntax `ds = horzcat(ds1, ds2, ...)`

Description `ds = horzcat(ds1, ds2, ...)` horizontally concatenates the dataset arrays `ds1`, `ds2`, You may concatenate dataset arrays that have duplicate variable names, however, the variables must contain identical data, and `horzcat` includes only one copy of the variable in the output dataset.

Observation names for all dataset arrays that have them must be identical except for order. `horzcat` concatenates by matching observation names when present, or by position for datasets that do not have observation names.

See Also `cat` | `vertcat`

Purpose Hougen-Watson model

Syntax `yhat = hougen(beta,x)`

Description `yhat = hougen(beta,x)` returns the predicted values of the reaction rate, `yhat`, as a function of the vector of parameters, `beta`, and the matrix of data, `X`. `beta` must have 5 elements and `X` must have three columns.

`hougen` is a utility function for `rsmdemo`.

The model form is:

$$\hat{y} = \frac{\beta_1 x_2 - x_3 / \beta_5}{1 + \beta_2 x_1 + \beta_3 x_2 + \beta_4 x_3}$$

References [1] Bates, D. M., and D. G. Watts. *Nonlinear Regression Analysis and Its Applications*. Hoboken, NJ: John Wiley & Sons, Inc., 1988.

See Also `rsmdemo`

hygecdf

Purpose Hypergeometric cumulative distribution function

Syntax `hygecdf(X,M,K,N)`

Description `hygecdf(X,M,K,N)` computes the hypergeometric cdf at each of the values in X using the corresponding size of the population, M , number of items with the desired characteristic in the population, K , and number of samples drawn, N . Vector or matrix inputs for X , M , K , and N must all have the same size. A scalar input is expanded to a constant matrix with the same dimensions as the other inputs.

The hypergeometric cdf is

$$p = F(x | M, K, N) = \sum_{i=0}^x \frac{\binom{K}{i} \binom{M-K}{N-i}}{\binom{M}{N}}$$

The result, p , is the probability of drawing up to x of a possible K items in N drawings without replacement from a group of M objects.

Examples Suppose you have a lot of 100 floppy disks and you know that 20 of them are defective. What is the probability of drawing zero to two defective floppies if you select 10 at random?

```
p = hygecdf(2,100,20,10)
p =
    0.6812
```

See Also `cdf` | `hygepdf` | `hygeinv` | `hygestat` | `hygernd`

Purpose	Hypergeometric inverse cumulative distribution function
Syntax	hygeinv(P,M,K,N)
Description	hygeinv(P,M,K,N) returns the smallest integer X such that the hypergeometric cdf evaluated at X equals or exceeds P . You can think of P as the probability of observing X defective items in N drawings without replacement from a group of M items where K are defective.
Examples	<p>Suppose you are the Quality Assurance manager for a floppy disk manufacturer. The production line turns out floppy disks in batches of 1,000. You want to sample 50 disks from each batch to see if they have defects. You want to accept 99% of the batches if there are no more than 10 defective disks in the batch. What is the maximum number of defective disks should you allow in your sample of 50?</p> <pre>x = hygeinv(0.99,1000,10,50) x = 3</pre> <p>What is the median number of defective floppy disks in samples of 50 disks from batches with 10 defective disks?</p> <pre>x = hygeinv(0.50,1000,10,50) x = 0</pre>
See Also	icdf hygecdf hygepdf hygestat hygernd

hygepdf

Purpose Hypergeometric probability density function

Syntax `Y = hygepdf(X,M,K,N)`

Description `Y = hygepdf(X,M,K,N)` computes the hypergeometric pdf at each of the values in `X` using the corresponding size of the population, `M`, number of items with the desired characteristic in the population, `K`, and number of samples drawn, `N`. `X`, `M`, `K`, and `N` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs.

The parameters in `M`, `K`, and `N` must all be positive integers, with $N \leq M$. The values in `X` must be less than or equal to all the parameter values.

The hypergeometric pdf is

$$y = f(x | M, K, N) = \frac{\binom{K}{x} \binom{M-K}{N-x}}{\binom{M}{N}}$$

The result, `y`, is the probability of drawing exactly `x` of a possible `K` items in `n` drawings without replacement from a group of `M` objects.

Examples Suppose you have a lot of 100 floppy disks and you know that 20 of them are defective. What is the probability of drawing 0 through 5 defective floppy disks if you select 10 at random?

```
p = hygepdf(0:5,100,20,10)
p =
    0.0951    0.2679    0.3182    0.2092    0.0841    0.0215
```

See Also `pdf` | `hygecdf` | `hygeinv` | `hygestat` | `hygernd`

Purpose	Hypergeometric random numbers
Syntax	<pre>R = hygernd(M,K,N) R = hygernd(M,K,N,m,n,...) R = hygernd(M,K,N,[m,n,...])</pre>
Description	<p>R = hygernd(M,K,N) generates random numbers from the hypergeometric distribution with corresponding size of the population, M, number of items with the desired characteristic in the population, K, and number of samples drawn, N. M, K, and N can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of R. A scalar input for M, K, or N is expanded to a constant array with the same dimensions as the other inputs.</p> <p>R = hygernd(M,K,N,m,n,...) or R = hygernd(M,K,N,[m,n,...]) generates an m-by-n-by-... array. The M, K, N parameters can each be scalars or arrays of the same size as R.</p>
Examples	<pre>numbers = hygernd(1000,40,50) numbers = 1</pre>
See Also	random hygepdf hygecdf hygeinv hygestat

hygestat

Purpose Hypergeometric mean and variance

Syntax `[MN,V] = hygestat(M,K,N)`

Description `[MN,V] = hygestat(M,K,N)` returns the mean of and variance for the hypergeometric distribution with corresponding size of the population, M, number of items with the desired characteristic in the population, K, and number of samples drawn, N. Vector or matrix inputs for M, K, and N must have the same size, which is also the size of MN and V. A scalar input for M, K, or N is expanded to a constant matrix with the same dimensions as the other inputs.

The mean of the hypergeometric distribution with parameters M, K, and N is NK/M , and the variance is $NK(M-K)(M-N) / [M^2(M-1)]$.

Examples The hypergeometric distribution approaches the binomial distribution, where $p = K/M$, as M goes to infinity.

```
[m,v] = hygestat(10.^(1:4),10.^(0:3),9)
m =
    0.9000    0.9000    0.9000    0.9000
v =
    0.0900    0.7445    0.8035    0.8094
```

```
[m,v] = binostat(9,0.1)
m =
    0.9000
v =
    0.8100
```

See Also `hygepdf` | `hygecdf` | `hygeinv` | `hygernd`

Purpose

Inverse cumulative distribution functions

Syntax

```
Y = icdf(name,X,A)
Y = icdf(name,X,A,B)
Y = icdf(name,X,A,B,C)
```

Description

`Y = icdf(name,X,A)` computes the inverse cumulative distribution function for the one-parameter family of distributions specified by `name`. Parameter values for the distribution are given in `A`. The inverse cumulative distribution function is evaluated at the values in `X` and its values are returned in `Y`.

If `X` and `A` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A`. If `A` is a scalar, it is expanded to a constant matrix the same size as `X`.

`Y` is the common size of `X` and `A` after any necessary scalar expansion.

`Y = icdf(name,X,A,B)` computes the inverse cumulative distribution function for two-parameter families of distributions, where parameter values are given in `A` and `B`.

If `X`, `A`, and `B` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A` and `B`. If either `A` or `B` are scalars, they are expanded to constant matrices the same size as `X`.

`Y` is the common size of `X`, `A`, and `B` after any necessary scalar expansion.

`Y = icdf(name,X,A,B,C)` computes the inverse cumulative distribution function for three-parameter families of distributions, where parameter values are given in `A`, `B`, and `C`.

If `X`, `A`, `B`, and `C` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A`, `B`, and `C`. If any of `A`, `B` or `C` are scalars, they are expanded to constant matrices the same size as `X`.

`Y` is the common size of `X`, `A`, `B` and `C` after any necessary scalar expansion.

Acceptable strings for `name` are:

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'beta' or 'Beta'	“Beta Distribution” on page B-4	a	b	—
'bino' or 'Binomial'	“Binomial Distribution” on page B-7	n: number of trials	p: probability of success for each trial	—
'birnbaumsaunders'	“Birnbau-Saunders Distribution” on page B-10	β	γ	—
'burr' or 'Burr'	“Burr Type XII Distribution” on page B-12	a: scale parameter	c: shape parameter	k: shape parameter
'chi2' or 'Chisquare'	“Chi-Square Distribution” on page B-25	ν : degrees of freedom	—	—
'exp' or 'Exponential'	“Exponential Distribution” on page B-29	μ : mean	—	—
'ev' or 'Extreme Value'	“Extreme Value Distribution” on page B-32	μ : location parameter	σ : scale parameter	—
'f' or 'F'	“F Distribution” on page B-38	ν_1 : numerator degrees of freedom	ν_2 : denominator degrees of freedom	—
'gam' or 'Gamma'	“Gamma Distribution” on page B-40	a: shape parameter	b: scale parameter	—
'gev' or 'Generalized Extreme Value'	“Generalized Extreme Value Distribution” on page B-45	k: shape parameter	σ : scale parameter	μ : location parameter

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'gp' or 'Generalized Pareto'	“Generalized Pareto Distribution” on page B-50	k: tail index (shape) parameter	σ : scale parameter	μ : threshold (location) parameter
'geo' or 'Geometric'	“Geometric Distribution” on page B-54	p: probability parameter	—	—
'hyge' or 'Hypergeometric'	“Hypergeometric Distribution” on page B-56	M: size of the population	K: number of items with the desired characteristic in the population	n: number of samples drawn
'inversegaussian'	“Inverse Gaussian Distribution” on page B-58	μ	λ	—
'logistic'	“Logistic Distribution” on page B-62	μ	σ	—
'loglogistic'	“Loglogistic Distribution” on page B-63	μ	σ	—
'logn' or 'Lognormal'	“Lognormal Distribution” on page B-64	μ	σ	—
'nakagami'	“Nakagami Distribution” on page B-83	μ	ω	—
'nbin' or 'Negative Binomial'	“Negative Binomial Distribution” on page B-85	r: number of successes	p: probability of success in a single trial	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'ncf' or 'Noncentral F'	“Noncentral F Distribution” on page B-91	ν_1 : numerator degrees of freedom	ν_2 : denominator degrees of freedom	δ : noncentrality parameter
'nct' or 'Noncentral t'	“Noncentral t Distribution” on page B-93	ν : degrees of freedom	δ : noncentrality parameter	—
'ncx2' or 'Noncentral Chi-square'	“Noncentral Chi-Square Distribution” on page B-89	ν : degrees of freedom	δ : noncentrality parameter	—
'norm' or 'Normal'	“Normal Distribution” on page B-96	μ : mean	σ : standard deviation	—
'poiss' or 'Poisson'	“Poisson Distribution” on page B-102	λ : mean	—	—
'ray1' or 'Rayleigh'	“Rayleigh Distribution” on page B-104	b : scale parameter	—	—
'rician'	“Rician Distribution” on page B-106	s : noncentrality parameter	σ : scale parameter	—
't' or 'T'	“Student’s t Distribution” on page B-108	ν : degrees of freedom	—	—
'tlocationscale'	“t Location-Scale Distribution” on page B-110	μ : location parameter	σ : scale parameter	ν : shape parameter
'unif' or 'Uniform'	“Uniform Distribution (Continuous)” on page B-112	a : lower endpoint (minimum)	b : upper endpoint (maximum)	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'unid' or 'Discrete Uniform'	“Uniform Distribution (Discrete)” on page B-114	N: maximum observable value	—	—
'wbl' or 'Weibull'	“Weibull Distribution” on page B-116	a: scale parameter	b: shape parameter	—

Examples

Compute the icdf of the normal distribution with mean 0 and standard deviation 1 at inputs 0.1, 0.3, ..., 0.9:

```
x1 = icdf('Normal',0.1:0.2:0.9,0,1)
x1 =
    -1.2816   -0.5244    0    0.5244    1.2816
```

The order of the parameters is the same as for `norminv`.

Compute the icdfs of Poisson distributions with rate parameters 0, 1, ..., 4 at inputs 0.1, 0.3, ..., 0.9, respectively:

```
x2 = icdf('Poisson',0.1:0.2:0.9,0:4)
x2 =
    NaN    0    2    4    7
```

The order of the parameters is the same as for `poissinv`.

See Also

`cdf` | `mle` | `pdf` | `random`

ProbDistUnivKernel.icdf

Purpose	Return inverse cumulative distribution function (ICDF) for ProbDistUnivKernel object	
Syntax	$Y = \text{icdf}(PD, P)$	
Description	$Y = \text{icdf}(PD, P)$ returns Y , an array containing the inverse cumulative distribution function (ICDF) for the ProbDistUnivKernel object PD , evaluated at values in P .	
Input Arguments	PD	An object of the class ProbDistUnivKernel.
	P	A numeric array of values from 0 to 1 where you want to evaluate the ICDF.
Output Arguments	Y	An array containing the inverse cumulative distribution function (ICDF) for the ProbDistUnivKernel object PD .
See Also	icdf	

Purpose	Return inverse cumulative distribution function (ICDF) for ProbDistUnivParam object	
Syntax	$Y = \text{icdf}(PD, P)$	
Description	$Y = \text{icdf}(PD, P)$ returns Y , an array containing the inverse cumulative distribution function (ICDF) for the ProbDistUnivParam object PD , evaluated at values in P .	
Input Arguments	PD	An object of the class ProbDistUnivParam.
	P	A numeric array of values from 0 to 1 where you want to evaluate the ICDF.
Output Arguments	Y	An array containing the inverse cumulative distribution function (ICDF) for the ProbDistUnivParam object PD .
See Also	icdf	

piecewisedistribution.icdf

Purpose Inverse cumulative distribution function for piecewise distribution

Syntax `X = icdf(obj,P)`

Description `X = icdf(obj,P)` returns an array `X` of values of the inverse cumulative distribution function for the piecewise distribution object `obj`, evaluated at the values in the array `P`.

Examples Fit Pareto tails to a t distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);
obj = paretotails(t,0.1,0.9);
[p,q] = boundary(obj)
p =
    0.1000
    0.9000
q =
   -1.7766
    1.8432

icdf(obj,p)
ans =
   -1.7766
    1.8432
```

See Also `paretotails` | `cdf`

Purpose Inconsistency coefficient

Syntax `Y = inconsistent(Z)`
`Y = inconsistent(Z,d)`

Description `Y = inconsistent(Z)` computes the inconsistency coefficient for each link of the hierarchical cluster tree Z , where Z is an $(m-1)$ -by-3 matrix generated by the linkage function. The inconsistency coefficient characterizes each link in a cluster tree by comparing its height with the average height of other links at the same level of the hierarchy. The higher the value of this coefficient, the less similar the objects connected by the link.

`Y = inconsistent(Z,d)` computes the inconsistency coefficient for each link in the hierarchical cluster tree Z to depth d , where d is an integer denoting the number of levels of the cluster tree that are included in the calculation. By default, $d=2$.

The output, Y , is an $(m-1)$ -by-4 matrix formatted as follows.

Column	Description
1	Mean of the heights of all the links included in the calculation.
2	Standard deviation of the heights of all the links included in the calculation.
3	Number of links included in the calculation.
4	Inconsistency coefficient.

For each link, k , the inconsistency coefficient is calculated as:

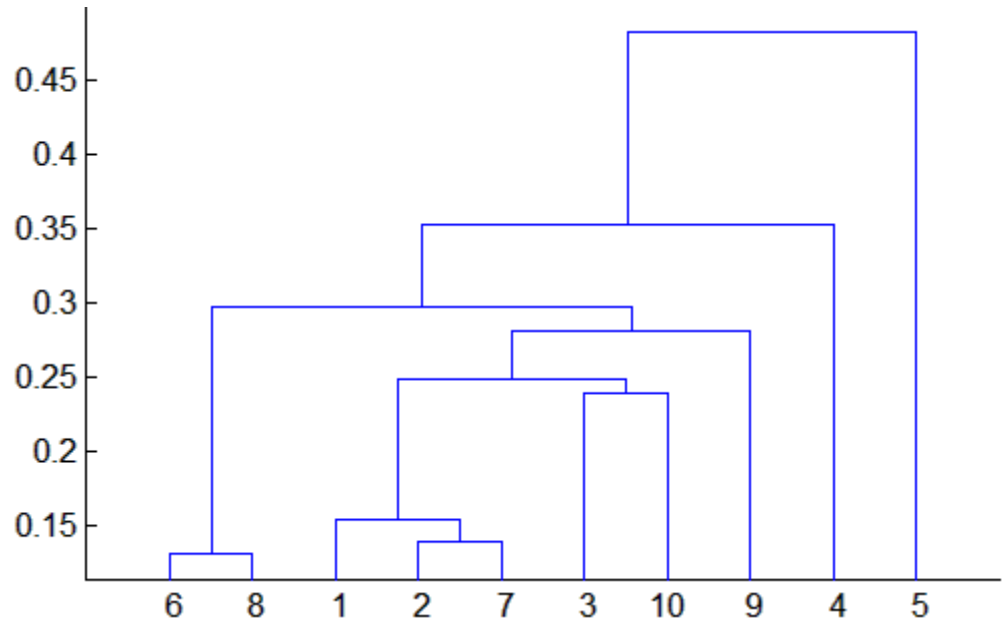
$$Y(k,4) = (z(k,3) - Y(k,1)) / Y(k,2)$$

For leaf nodes, nodes that have no further nodes under them, the inconsistency coefficient is set to 0.

inconsistent

Examples

```
X = gallery('uniformdata',[10 2],12);  
Y = pdist(X);  
Z = linkage(Y,'single');  
dendrogram(Z)
```



```
W = inconsistent(Z,3)
```

```
W =
```

0.1313	0	1.0000	0
0.1386	0	1.0000	0
0.1463	0.0109	2.0000	0.7071
0.2391	0	1.0000	0
0.1951	0.0568	4.0000	0.9425
0.2308	0.0543	4.0000	0.9320
0.2395	0.0748	4.0000	0.7636
0.2654	0.0945	4.0000	0.9203
0.3769	0.0950	3.0000	1.1040

References

[1] Jain, A., and R. Dubes. *Algorithms for Clustering Data*. Upper Saddle River, NJ: Prentice-Hall, 1988.

[2] Zahn, C. T. "Graph-theoretical methods for detecting and describing Gestalt clusters." *IEEE Transactions on Computers*. Vol. C-20, Issue 1, 1971, pp. 68–86.

See Also

`cluster` | `cophenet` | `clusterdata` | `dendrogram` | `linkage` | `pdist` | `squareform`

ProbDist.InputData property

Purpose Read-only structure containing information about input data to ProbDist object

Description InputData is a read-only property of the ProbDist class. InputData is a structure containing information about input data to a ProbDist object. It includes the following fields:

- data
- cens
- freq

Values Possible values for the three fields in the structure are any data supplied to the `fitdist` function:

- `data` — Data passed to the `fitdist` function when creating the ProbDist object. This field is empty if the ProbDist object was created without fitting to data, that is by using the `ProbDistUnivParam.ProbDistUnivParam` constructor.
- `cens` — The vector supplied with the 'censoring' parameter when creating the ProbDist object using the `fitdist` function. This field is empty if the ProbDist object was created without fitting to data, that is by using the `ProbDistUnivParam.ProbDistUnivParam` constructor.
- `freq` — The vector supplied with the 'frequency' parameter when creating the ProbDist object using the `fitdist` function. This field is empty if the ProbDist object was created without fitting to data, that is by using the `ProbDistUnivParam.ProbDistUnivParam` constructor.

Use this information to view and compare the data supplied to create distributions.

Purpose	Convert categorical array to signed 8-bit integer array
Syntax	<code>B = int8(A)</code>
Description	<p><code>B = int8(A)</code> converts the categorical array <code>A</code> to a signed 8-bit integer array. Each element of <code>B</code> contains the internal categorical level code for the corresponding element of <code>A</code>.</p> <p>Undefined elements of <code>A</code> are assigned the value 0 in <code>B</code>. If <code>A</code> contains more than <code>intmax('int8')</code> levels, the internal codes will saturate to <code>intmax('int8')</code> when cast to <code>int8</code>.</p>
See Also	<code>double</code> <code>uint8</code>
How To	<ul style="list-style-type: none">• “Integers”

categorical.int16

Purpose Convert categorical array to signed 16-bit integer array

Syntax `B = int16(A)`

Description `B = int16(A)` converts the categorical array `A` to a signed 16-bit integer array. Each element of `B` contains the internal categorical level code for the corresponding element of `A`.

Undefined elements of `A` are assigned the value 0 in `B`.

See Also `double` | `uint16`

How To • “Integers”

Purpose Convert categorical array to signed 32-bit integer array

Syntax `B = int32(A)`

Description `B = int32(A)` converts the categorical array `A` to a signed 32-bit integer array. Each element of `B` contains the internal categorical level code for the corresponding element of `A`.

Undefined elements of `A` are assigned the value 0 in `B`.

See Also `double` | `uint32`

How To

- “Integers”

categorical.int64

Purpose Convert categorical array to signed 64-bit integer array

Syntax `B = int64(A)`

Description `B = int64(A)` converts the categorical array `A` to a signed 64-bit integer array. Each element of `B` contains the internal categorical level code for the corresponding element of `A`.

Undefined elements of `A` are assigned the value 0 in `B`.

See Also `double` | `uint64`

How To

- “Integers”

Purpose

Interaction plot for grouped data

Syntax

```
interactionplot(Y,GROUP)
interactionplot(Y,GROUP,'varnames',VARNAMES)
[h,AX,bigax] = interactionplot(...)
```

Description

`interactionplot(Y,GROUP)` displays the two-factor interaction plot for the group means of matrix `Y` with groups defined by entries in the cell array `GROUP`. `Y` is a numeric matrix or vector. If `Y` is a matrix, the rows represent different observations and the columns represent replications of each observation. If `Y` is a vector, the rows give the means of each entry in the cell array `GROUP`. Each cell of `GROUP` must contain a grouping variable that can be a categorical variable, numeric vector, character matrix, or a single-column cell array of strings. `GROUP` can also be a matrix whose columns represent different grouping variables. Each grouping variable must have the same number of rows as `Y`. The number of grouping variables must be greater than 1.

The interaction plot is a matrix plot, with the number of rows and columns both equal to the number of grouping variables. The grouping variable names are printed on the diagonal of the plot matrix. The plot at off-diagonal position (i,j) is the interaction of the two variables whose names are given at row diagonal (i,i) and column diagonal (j,j) , respectively.

`interactionplot(Y,GROUP,'varnames',VARNAMES)` displays the interaction plot with user-specified grouping variable names `VARNAMES`. `VARNAMES` is a character matrix or a cell array of strings, one per grouping variable. Default names are 'X1', 'X2',

`[h,AX,bigax] = interactionplot(...)` returns a handle `h` to the figure window, a matrix `AX` of handles to the subplot axes, and a handle `bigax` to the big (invisible) axes framing the subplots.

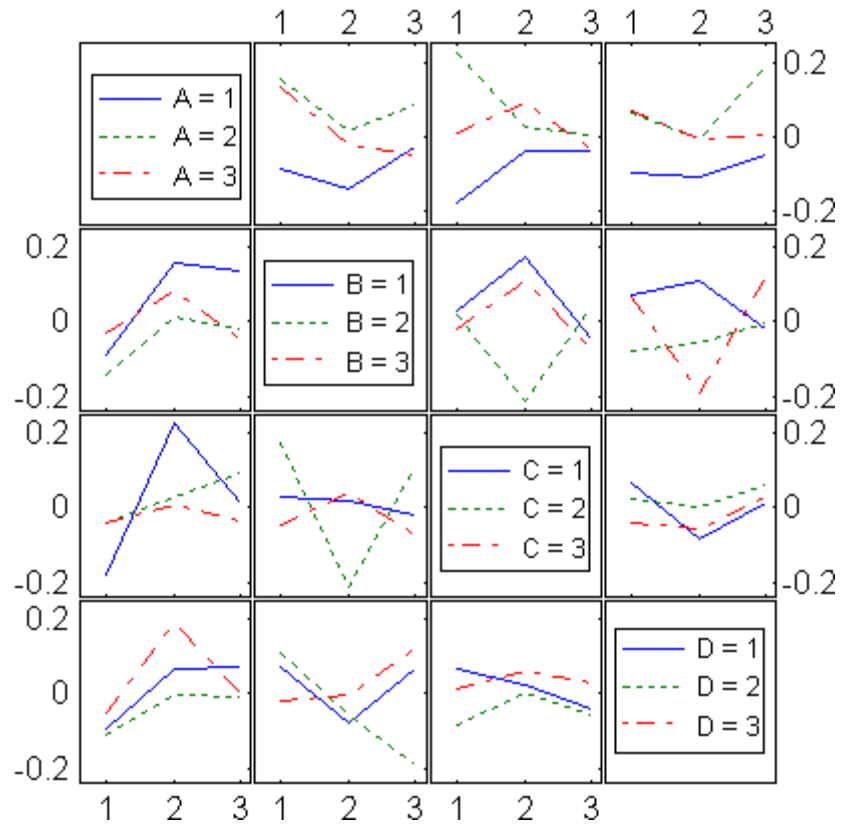
Examples

Display interaction plots for data with four 3-level factors named 'A', 'B', 'C', and 'D':

```
y = randn(1000,1); % response
```

interactionplot

```
group = ceil(3*rand(1000,4)); % four 3-level factors  
interactionplot(y,group,'varnames',{'A','B','C','D'})
```



See Also

[maineffectsplo](#) | [multivarichart](#)

How To

- “Grouping Variables” on page 2-72

Purpose Set intersection for categorical arrays

Note In a future release, the behavior of `categorical.intersect` will change to be consistent with the MATLAB function `intersect`. This behavior change is optional in R2012a. For a demonstration of using the 'R2012a' flag to preview the future behavior, or the 'legacy' flag to preserve the current behavior in your existing code, see the documentation for `intersect`.

Syntax

```
C = intersect(A,B)
[C,IA,IB] = intersect(A,B)
[...] = intersect(A,B,'rows')
[...] = intersect(...,'R2012a')
[...] = intersect(...,'legacy')
[...] = intersect(A,B,setOrder)
[...] = intersect(A,B,'rows',setOrder)
```

Description `C = intersect(A,B)` for categorical vectors A and B, returns a categorical vector C containing the values common to the two vectors with no repetitions. The result C is sorted. The set of categorical levels for C is the sorted union of the sets of levels of the inputs.

`[C,IA,IB] = intersect(A,B)` also returns index vectors IA and IB such that `C = A(IA)` and `C = B(IB)`. If there are repeated common values in A or B, then the index of the last occurrence of each repeated value is returned.

`[...] = intersect(A,B,'rows')` for categorical matrices A and B with the same number of columns, returns the rows common to the two matrices. The rows of the matrix C are sorted. The set of categorical levels for C is the sorted union of the sets of levels of the inputs. The optional outputs IA and IB are index vectors such that `C = A(IA,:)` and `C = B(IB,:)`.

categorical.intersect

`[...] = intersect(..., 'R2012a')` adopts the future behavior of `intersect`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `B`, or `'rows'`.

`[...] = intersect(..., 'legacy')` preserves the current behavior of `intersect`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `B`, or `'rows'`.

`[...] = intersect(A,B,setOrder)` and `[...] = intersect(A,B, 'rows', setOrder)` returns the observations of `C` in a specific order. `setOrder='sorted'` returns the values or rows of `C` in sorted order. `setOrder='stable'` returns the values or rows of `C` in the same order as `A`. If `A` and `B` are row vectors, then `C` is also a row vector. Otherwise, `C` is a column vector. If `A` and `B` are column vectors. If there are repeated common values in `A` or `B`, then the index of the first occurrence of each repeated value is returned.

See Also

`ismember` | `setdiff` | `setxor` | `union` | `unique`

Purpose	Set intersection for dataset array observations
Syntax	<pre>C = intersect(A,B) C = intersect(A,B,vars) C = intersect(A,B,vars,setOrder) [C,iA,iB] = intersect(___)</pre>
Description	<p><code>C = intersect(A,B)</code> for dataset arrays <code>A</code> and <code>B</code> returns the common set of observations from the two arrays, with repetitions removed. The observations in the dataset array <code>C</code> are in sorted order.</p> <p><code>C = intersect(A,B,vars)</code> returns the set of common observations from the two arrays, considering only the variables specified in <code>vars</code>, with repetitions removed. The observations in the dataset array <code>C</code> are sorted by those variables.</p> <p>The values for variables not specified in <code>vars</code> for each observation in <code>C</code> are taken from the corresponding observations in <code>A</code>. If there are multiple observations in <code>A</code> that correspond to an observation in <code>C</code>, then those values are taken from the first occurrence.</p> <p><code>C = intersect(A,B,vars,setOrder)</code> returns the observations in <code>C</code> in the order specified by <code>setOrder</code>.</p> <p><code>[C,iA,iB] = intersect(___)</code> also returns index vectors <code>iA</code> and <code>iB</code> such that <code>C = A(iA,:)</code> and <code>C = B(iB,:)</code>. If there are repeated observations in <code>A</code> or <code>B</code>, then <code>intersect</code> returns the index of the first occurrence. You can use any of the previous input arguments.</p>
Input Arguments	<p>A,B Input dataset arrays.</p> <p>vars Cell array of strings containing variable names or a vector of integers containing variable column numbers, indicating the variables in <code>A</code> and <code>B</code> that <code>intersect</code> considers.</p> <p>Specify <code>vars</code> as <code>[]</code> to use its default value of all variables.</p>

dataset.intersect

setOrder

Flag indicating the sorting order for the observations in C. The possible values of setOrder are:

- | | |
|----------|--|
| 'sorted' | Observations in C are in sorted order (default). |
| 'stable' | Observations in C are in the same order that they appear in A. |

Output Arguments

C

Dataset array with the common set of observations in A and B, with repetitions removed. C is in sorted order (by default), or the order specified by setOrder.

iA

Index vector, indicating the observations in A that are common to B. The vector iA contains the index to the first occurrence of any repeated observations in A.

iB

Index vector, indicating the observations in B that are common to A. The vector iB contains the index to the first occurrence of any repeated observations in B.

Examples

Intersection of Two Dataset Arrays

Load sample data.

```
A = dataset('XLSFile','hospitalSmall.xlsx');  
B = dataset('XLSFile','hospitalSmall.xlsx','Sheet',2);
```

Return the intersection and index vectors.

```
[C,iA,iB] = intersect(A,B);
```

```
C =
```

id	name	sex	age	wgt	smoke
'TRW-072'	'WHITE'	'm'	39	202	1

There is one observation in common between A and B.

Find the observation in the original dataset arrays.

```
A(iA,:) 
```

```
ans =
```

id	name	sex	age	wgt	smoke
'TRW-072'	'WHITE'	'm'	39	202	1

```
B(iB,:) 
```

```
ans =
```

id	name	sex	age	wgt	smoke
'TRW-072'	'WHITE'	'm'	39	202	1

See Also

[dataset](#) | [ismember](#) | [setdiff](#) | [setxor](#) | [sortrows](#) | [union](#) | [unique](#) |

Related Examples

- “Merge Dataset Arrays” on page 2-122

Concepts

- “Dataset Arrays” on page 2-156

invpred

Purpose Inverse prediction

Syntax
 $X0 = \text{invpred}(X, Y, Y0)$
 $[X0, DXLO, DXUP] = \text{invpred}(X, Y, Y0)$
 $[X0, DXLO, DXUP] = \text{invpred}(X, Y, Y0, name1, val1, name2, val2, \dots)$

Description $X0 = \text{invpred}(X, Y, Y0)$ accepts vectors X and Y of the same length, fits a simple regression, and returns the estimated value $X0$ for which the height of the line is equal to $Y0$. The output, $X0$, has the same size as $Y0$, and $Y0$ can be an array of any size.

$[X0, DXLO, DXUP] = \text{invpred}(X, Y, Y0)$ also computes 95% inverse prediction intervals. $DXLO$ and $DXUP$ define intervals with lower bound $X0 - DXLO$ and upper bound $X0 + DXUP$. Both $DXLO$ and $DXUP$ have the same size as $Y0$.

The intervals are not simultaneous and are not necessarily finite. Some intervals may extend from a finite value to $-\text{Inf}$ or $+\text{Inf}$, and some may extend over the entire real line.

$[X0, DXLO, DXUP] = \text{invpred}(X, Y, Y0, name1, val1, name2, val2, \dots)$ specifies optional argument name/value pairs chosen from the following list. Argument names are case insensitive and partial matches are allowed.

Name	Value
'alpha'	A value between 0 and 1 specifying a confidence level of $100 * (1 - \text{alpha})\%$. Default is $\text{alpha} = 0.05$ for 95% confidence.
'predopt'	Either 'observation', the default value to compute the intervals for $X0$ at which a new observation could equal $Y0$, or 'curve' to compute intervals for the $X0$ value at which the curve is equal to $Y0$.

Examples

```
x = 4*rand(25,1);  
y = 10 + 5*x + randn(size(x));  
scatter(x,y)  
x0 = invpred(x,y,20)
```

See Also

[polyfit](#) | [polyval](#) | [polyconf](#) | [polytool](#)

categorical.ipermute

Purpose Inverse permute dimensions of categorical array

Syntax `A = ipermute(B,order)`

Description `A = ipermute(B,order)` is the inverse of `permute`. `ipermute` rearranges the dimensions of the categorical array `B` so that `permute(A,order)` will produce `B`. The array produced has the same values of `A` but the order of the subscripts needed to access any particular element are rearranged as specified by `order`. The elements of `order` must be a rearrangement of the numbers from 1 to `n`.

See Also `permute`

Purpose	Interquartile range
Syntax	<pre>y = iqr(X) iqr(X,dim)</pre>
Description	<p><code>y = iqr(X)</code> returns the interquartile range of the values in <code>X</code>. For vector input, <code>y</code> is the difference between the 75th and the 25th percentiles of the sample in <code>X</code>. For matrix input, <code>y</code> is a row vector containing the interquartile range of each column of <code>X</code>. For N-dimensional arrays, <code>iqr</code> operates along the first nonsingleton dimension of <code>X</code>.</p> <p><code>iqr(X,dim)</code> calculates the interquartile range along the dimension <code>dim</code> of <code>X</code>.</p>
Tips	<p>The IQR is a robust estimate of the spread of the data, since changes in the upper and lower 25% of the data do not affect it. If there are outliers in the data, then the IQR is more representative than the standard deviation as an estimate of the spread of the body of the data. The IQR is less efficient than the standard deviation as an estimate of the spread when the data is all from the normal distribution.</p> <p>Multiply the IQR by 0.7413 to estimate σ (the second parameter of the normal distribution.)</p>
Examples	<p>This Monte Carlo simulation shows the relative efficiency of the IQR to the sample standard deviation for normal data.</p> <pre>x = normrnd(0,1,100,100); s = std(x); s_IQR = 0.7413*iqr(x); efficiency = (norm(s-1)./norm(s_IQR-1)).^2 efficiency = 0.3297</pre>
See Also	<code>std</code> <code>mad</code> <code>range</code>

ProbDistUnivKernel.iqr

Purpose	Return interquartile range (IQR) for ProbDistUnivKernel object	
Syntax	$Y = \text{iqr}(PD)$	
Description	$Y = \text{iqr}(PD)$ returns Y , the interquartile range for the ProbDistUnivKernel object PD . The interquartile range is the distance between the 75th and 25th percentiles.	
Input Arguments	PD	An object of the class ProbDistUnivKernel.
Output Arguments	Y	The value of the interquartile range for the ProbDistUnivKernel object PD .
See Also	iqr ProbDistUnivKernel.icdf	

Purpose	Return interquartile range (IQR) for ProbDistUnivParam object		
Syntax	$Y = \text{iqr}(PD)$		
Description	$Y = \text{iqr}(PD)$ returns Y , the interquartile range for the ProbDistUnivParam object PD . The interquartile range is the distance between the 75th and 25th percentiles.		
Input Arguments	<table><tr><td>PD</td><td>An object of the class ProbDistUnivParam.</td></tr></table>	PD	An object of the class ProbDistUnivParam.
PD	An object of the class ProbDistUnivParam.		
Output Arguments	<table><tr><td>Y</td><td>The value of the interquartile range for the ProbDistUnivParam object PD.</td></tr></table>	Y	The value of the interquartile range for the ProbDistUnivParam object PD .
Y	The value of the interquartile range for the ProbDistUnivParam object PD .		
See Also	iqr ProbDistUnivParam.icdf		

classregtree.isbranch

Purpose Test node for branch

Syntax `ib = isbranch(t)`
`ib = isbranch(t,nodes)`

Description `ib = isbranch(t)` returns an n -element logical vector `ib` that is true for each branch node and false for each leaf node.

`ib = isbranch(t,nodes)` takes a vector `nodes` of node numbers and returns a vector of logical values for the specified nodes.

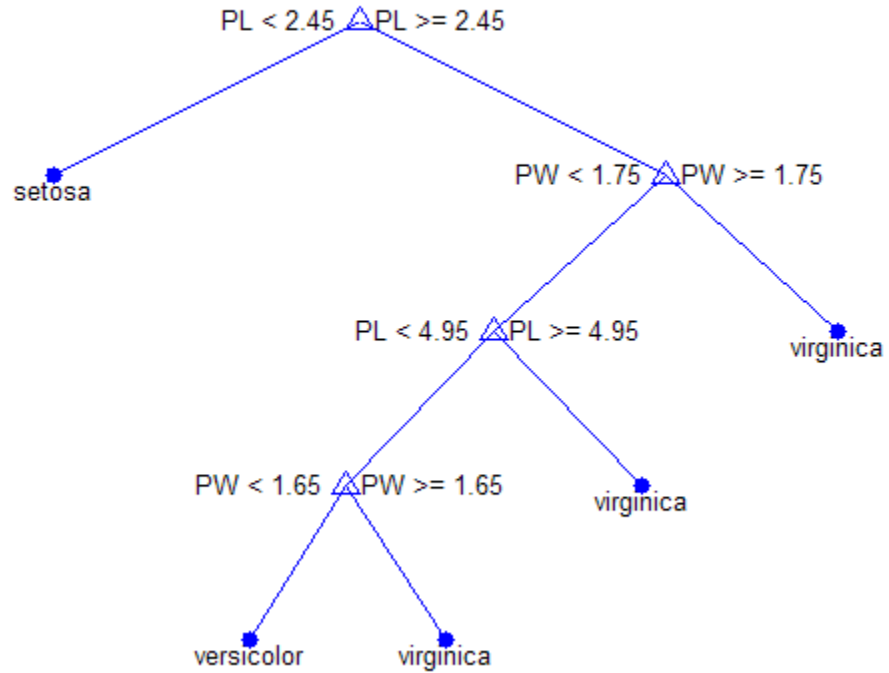
Examples Create a classification tree for Fisher's iris data:

```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

Click to display: Magnification: Pruning level:



```
ib = isbranch(t)
```

```
ib =
    1
    0
    1
    1
    0
    1
    0
    0
```

classregtree.isbranch

0

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

`classregtree` | `cutvar` | `numnodes`

Purpose True for empty categorical array

Syntax TF = isEmpty(A)

Description TF = isEmpty(A) returns true (1) if A is an empty categorical array and false (0) otherwise. An empty array has no elements, that is numel(A)==0.

See Also numel | size

dataset.isempty

Purpose True for empty dataset array

Syntax `tf = isempty(A)`

Description `tf = isempty(A)` returns true (1) if A is an empty dataset and false (0) otherwise. An empty array has no elements, that is `prod(size(A))==0`.

See Also `size`

Purpose True if categorical arrays are equal

Syntax TF = isequal(A,B)
TF = isequal(A,B,C,...)

Description TF = isequal(A,B) is true (1) if the categorical arrays A and B are the same class, have the same size and the same sets of levels, and contain the same values, and false (0) otherwise.

TF = isequal(A,B,C,...) is true (1) if all the input arguments are equal.

Elements with undefined levels are not considered equal to each other.

See Also getlabels

categorical.islevel

Purpose Test for levels

Syntax `I = islevel(levels,A)`

Description `I = islevel(levels,A)` returns a logical array `I` the same size as the string, cell array of strings, or 2-D character matrix `levels`. `I` is true (1) where the corresponding element of `levels` is the label of a level in the categorical array `A`, even if the level contains no elements. `I` is false (0) otherwise.

Examples Display age levels in the data in `hospit1.mat`, before and after dropping occupied levels:

```
load hospital
edges = 0:10:100;
labels = strcat(num2str((0:10:90)','%d'),{'s'});
disp(labels')
'0s' '10s' '20s' '30s' '40s' '50s' '60s' '70s' '80s' '90s'

AgeGroup = ordinal(hospital.Age,labels,[],edges);
I = islevel(labels,AgeGroup);
disp(I')
1 1 1 1 1 1 1 1 1 1

AgeGroup = droplevels(AgeGroup);
I = islevel(labels,AgeGroup);
disp(I')
0 0 1 1 1 1 0 0 0 0
```

See Also `ismember` | `isundefined`

Purpose

Test for membership

Syntax

```
I = ismember(A,levels)
[I,IDX] = ismember(A,levels)
```

Description

`I = ismember(A,levels)` returns a logical array `I` the same size as the categorical array `A`. `I` is true (1) where the corresponding element of `A` is one of the levels specified by the labels in the categorical array, cell array of strings, or 2-D character array `levels`. `I` is false (0) otherwise.

`[I,IDX] = ismember(A,levels)` also returns an array of indices `IDX` containing the highest absolute index in `levels` for each element in `A` whose level is a member of `levels`, and 0 if there is no such index.

Examples

Example 1

For nominal data:

```
load hospital
sex = hospital.Sex; % Nominal
smokers = hospital.Smoker; % Logical
I = ismember(sex(smokers),'Female');
I(1:5)
ans =
     0
     1
     0
     0
     0
```

The use of `ismember` above is equivalent to:

```
I = (sex(smokers) == 'Female');
```

Example 2

For ordinal data:

```
load hospital
edges = 0:10:100;
```

ordinal.ismember

```
labels = strcat(num2str((0:10:90)', '%d'), {'s'});
AgeGroup = ordinal(hospital.Age, labels, [], edges);
I = ismember(AgeGroup(1:5), {'20s', '30s'})
I =
     1
     0
     1
     0
     0
```

See Also [islevel](#) | [isundefined](#)

Purpose True for elements of categorical array in set

Note In a future release, the behavior of `categorical.ismember` will change to be consistent with the MATLAB function `ismember`. This behavior change is optional in R2012a. For a demonstration of using the 'R2012a' flag to preview the future behavior, or the 'legacy' flag to preserve the current behavior in your existing code, see the documentation for `ismember`.

Syntax

```
TF = ismember(A,B)
[TF,LOCB] = ismember(A,B)
[...] = ismember(A,B,'rows')
[...] = intersect(...,'R2012a')
[...] = intersect(...,'legacy')
```

Description `TF = ismember(A,B)` for categorical arrays `A` and `B`, returns a logical array the same size as `A`, containing true (1) where the elements of `A` are in `B`, and false (0) otherwise. `B` can also be a cell array of strings or two-dimensional character array containing level labels.

`[TF,LOCB] = ismember(A,B)` also returns an index array `LOCB` containing the highest absolute index in `B` for each element in `A` which is a member of `B`, and 0 if there is no such index.

`[...] = ismember(A,B,'rows')`, for categorical matrices `A` and `B` with the same number of columns, returns a logical vector containing true (1) where the rows of `A` are also rows of `B`, and false (0) otherwise. The optional output `LOCB` is an index vector containing the highest absolute index in `B` for each row in `A` which is a member of `B` and 0 if there is no such index.

`[...] = intersect(...,'R2012a')` adopts the future behavior of `ismember`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `B`, or 'rows'.

categorical.ismember

[...] = intersect(..., 'legacy') preserves the current behavior of ismember. You can specify the flag as the final argument with any previous syntax that accepts A, B, or 'rows'.

See Also

intersect | islevel | setdiff | setxor | union | unique

Purpose

Dataset array elements that are members of set

Syntax

```
LiA = ismember(A,B)  
LiA = ismember(A,B,vars)  
[LiA,LocB] = ismember( ___ )
```

Description

`LiA = ismember(A,B)` for dataset arrays `A` and `B` returns a vector of logical values the same length as `A`. The output vector, `LiA`, has value 1 (true) in the elements that correspond to observations in `A` that are also present in `B`, and 0 (false) otherwise.

`LiA = ismember(A,B,vars)` returns a vector of logical values the same length as `A`. The output vector, `LiA`, has value 1 (true) in the elements that correspond to observations in `A` that are also present in `B` for the variables specified in `vars` only, and 0 (false) otherwise.

`[LiA,LocB] = ismember(___)` also returns a vector the same length as `A` containing the index to the first observation in `B` that corresponds to each observation in `A`, or 0 if there is no such observation. You can use any of the previous input arguments.

Input Arguments

A

Query dataset array, containing the observations to be found in `B`.

B

Set dataset array. When an observation in `A` is found in `B`, for all variables or only those variables specified in `vars`, the corresponding element of `LiA` is 1.

vars

Cell array of strings containing variable names or a vector of integers containing variable column numbers, indicating which variables to match observations on in `A` and `B`.

dataset.ismember

Output Arguments

LiA

Vector of logical values the same length as A. LiA has value 1 (true) when the corresponding observation in A is present in B. Otherwise, LiA has value 0 (false).

If you specify `vars`, LiA has value 1 when the corresponding observation in A is present in B for the variables in `vars` only.

LocB

Vector the same length as A containing the index to the first observation in B that corresponds to each observation in A, for all variables or only those variables specified in `vars`.

Examples

Find Observations That Are Members of a Dataset Array

Load sample data.

```
load('hospital')  
B = hospital(1:50,1:5);
```

This set dataset array, B, has 50 observations on 5 variables.

Specify a query dataset array.

```
rng('default')  
rIx = randsample(100,10);  
A = hospital(rIx,1:5)
```

A =

	LastName	Sex	Age	Weight	Smoker
YLN-495	'COLEMAN'	Male	39	188	false
LQW-768	'TAYLOR'	Female	31	132	false
DGC-290	'BUTLER'	Male	38	184	true
DAU-529	'REED'	Male	50	186	true
REV-997	'ALEXANDER'	Male	25	171	true
QEQ-082	'COX'	Female	28	111	false
AGR-528	'SIMMONS'	Male	45	181	false

PUE-347	'YOUNG'	Female	25	114	false
HVR-372	'RUSSELL'	Male	44	188	true
XUE-826	'JACKSON'	Male	25	174	false

Check which observations in A are present in B.

```
LiA = ismember(A,B)
```

```
LiA =
```

```
0
1
0
0
0
0
0
0
1
0
1
```

Display the observations in A that are present in B.

```
A(LiA,:)
```

```
ans =
```

	LastName	Sex	Age	Weight	Smoker
LQW-768	'TAYLOR'	Female	31	132	false
PUE-347	'YOUNG'	Female	25	114	false
XUE-826	'JACKSON'	Male	25	174	false

Find the location of the observations in B.

```
[~,LocB] = ismember(A,B)
```

```
LocB =
```

dataset.ismember

```
0
10
0
0
0
0
0
28
0
13
```

Display the observations in B that match observations in A.

```
B(LocB(LocB>0), :)
```

```
ans =
```

	LastName	Sex	Age	Weight	Smoker
LQW-768	'TAYLOR'	Female	31	132	false
PUE-347	'YOUNG'	Female	25	114	false
XUE-826	'JACKSON'	Male	25	174	false

See Also

`dataset` | `intersect` | `setdiff` | `setxor` | `sortrows` | `union` | `unique` |

Concepts

- “Dataset Arrays” on page 2-156

Purpose Find dataset array elements with missing values

Syntax

```
I = ismissing(ds)  
I = ismissing(ds,Name,Value)
```

Description `I = ismissing(ds)` returns a logical array that indicates which elements in the dataset array, `ds`, contain a missing value. By default, `ismissing` recognizes NaN as a missing value in numeric variables, '' as a missing value in string variables, and <undefined> as a missing value in categorical arrays.

- `ds2 = ds(~any(I,2),:)` creates a new dataset array containing only the complete observations in `ds`.
- `ds2 = ds(:,~any(I,1))` creates a new dataset array containing only the variables from `ds` with no missing values.

`I = ismissing(ds,Name,Value)` returns missing value indices with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ds
dataset array

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

NumericTreatAsMissing

dataset.ismissing

Vector of numeric values to treat as missing value indicators in floating point `ds` variables. `ismissing` always treats a NaN value as a missing value.

StringTreatAsMissing

String or cell array of strings to treat as missing value indicators in string `ds` variables. `ismissing` always treats the empty string `''` as a missing value.

Output Arguments

I

Logical array indicating which elements in `ds` contain a missing value. `I` is the same size as `ds`, with value 1 for elements that contain a missing value.

See Also

`dataset` | `isempty` | `isnanisundefined` | `replaceWithMissing` |

Related Examples

- “Clean Messy and Missing Data” on page 2-138

Concepts

- “Dataset Arrays” on page 2-156

Purpose True if categorical array is scalar

Syntax TF = isscalar(A)

Description TF = isscalar(A) returns true (1) if the categorical array A is a 1-by-1 matrix, and false (0) otherwise.

See Also isempty | isvector | size

categorical.isundefined

Purpose Test for undefined elements

Syntax `I = isundefined(A)`

Description `I = isundefined(A)` returns a logical array `I` the same size as the categorical array `A`. `I` is true (1) where the corresponding element of `A` is not assigned to any level. `I` is false (0) where the corresponding element of `A` is assigned to a level.

Examples Create and display undefined levels in an ordinal array:

```
A = ordinal([1 2 3 2 1],{'lo','med','hi'})
```

```
A =  
    lo      med      hi      med      lo
```

```
A = droplevels(A,{'med','hi'})
```

Warning: OLDLEVELS contains categorical levels that were present in A, caused some array elements to have undefined levels.

```
A =  
    lo <undefined> <undefined> <undefined> lo
```

```
I = isundefined(A)
```

```
I =  
    0     1     1     1     0
```

See Also `islevel` | `ismember`

Purpose Test handle validity

Syntax `tf = isvalid(h)`

Description `tf = isvalid(h)` performs an element-wise check for validity on the handle elements of `h`. The result is a logical array of the same dimensions as `h`, where each element is the element-wise validity result.

A handle is invalid if it has been deleted or if it is an element of a handle array and has not yet been initialized.

See Also `delete` | `grandstream`

categorical.isvector

Purpose True if categorical array is vector

Syntax TF = isvector(A)

Description TF = isvector(A) returns true (1) if the categorical array A is a 1-by-n or n-by-1 vector, where n >= 0, and false (0) otherwise.

See Also isempty | isscalar | size

gmdistribution.Iters property

Purpose Number of iterations

Description The number of iterations of the algorithm.

Note This property applies only to gmdistribution objects constructed with `fit`.

iwishrnd

Purpose Inverse Wishart random numbers

Syntax
`W = wishrnd(Tau,df)`
`W = wishrnd(Tau,df,DI)`
`[W,DI] = wishrnd(Tau,df)`

Description `W = wishrnd(Tau,df)` generates a random matrix `W` from the inverse Wishart distribution with parameters `Tau` and `df`. The inverse of `W` has the Wishart distribution with covariance matrix `Sigma = inv(Tau)` and with `df` degrees of freedom. `Tau` is a symmetric and positive definite matrix.

`W = wishrnd(Tau,df,DI)` expects `DI` to be the transpose of the inverse of the Cholesky factor of `Tau`, so that `DI'*DI = inv(Tau)`, where `inv` is the MATLAB inverse function. `DI` is lower-triangular and the same size as `Tau`. If you call `wishrnd` multiple times using the same value of `Tau`, it is more efficient to supply `DI` instead of computing it each time.

`[W,DI] = wishrnd(Tau,df)` returns `DI` so you can use it as an input in future calls to `wishrnd`.

Note that different sources use different parametrizations for the inverse Wishart distribution. This function defines the parameter `tau` so that the mean of the output matrix is `Tau / (df-d-1)` where `d` is the dimension of `Tau`.

See Also `wishrnd`

How To • “Inverse Wishart Distribution” on page B-59

Purpose

Jackknife sampling

Syntax

```
jackstat = jackknife(jackfun,X)
jackstat = jackknife(jackfun,X,Y,...)
jackstat = jackknife(jackfun,...,'Options',option)
```

Description

`jackstat = jackknife(jackfun,X)` draws jackknife data samples from the n -by- p data array `X`, computes statistics on each sample using the function `jackfun`, and returns the results in the matrix `jackstat`. `jackknife` regards each row of `X` as one data sample, so there are n data samples. Each of the n rows of `jackstat` contains the results of applying `jackfun` to one jackknife sample. `jackfun` is a function handle specified with `@`. Row i of `jackstat` contains the results for the sample consisting of `X` with the i th row omitted:

```
s = x;
s(i,:) = [];
jackstat(i,:) = jackfun(s);
```

If `jackfun` returns a matrix or array, then this output is converted to a row vector for storage in `jackstat`. If `X` is a row vector, it is converted to a column vector.

`jackstat = jackknife(jackfun,X,Y,...)` accepts additional arguments to be supplied as inputs to `jackfun`. They may be scalars, column vectors, or matrices. `jackknife` creates each jackknife sample by sampling with replacement from the rows of the non-scalar data arguments (these must have the same number of rows). Scalar data are passed to `jackfun` unchanged. Non-scalar arguments must have the same number of rows, and each jackknife sample omits the same row from these arguments.

`jackstat = jackknife(jackfun,...,'Options',option)` provides an option to perform jackknife iterations in parallel, if the Parallel Computing Toolbox is available. Set 'Options' as a structure you create with `statset`. `jackknife` uses the following field in the structure:

'UseParallel' If 'always' and if a matlabpool of the Parallel Computing Toolbox is open, use multiple processors to compute jackknife iterations. If the Parallel Computing Toolbox is not installed, or a matlabpool is not open, computation occurs in serial mode. Default is 'never', or serial computation.

Examples

Estimate the bias of the MLE variance estimator of random samples taken from the vector y using `jackknife`. The bias has a known formula in this problem, so you can compare the `jackknife` value to this formula.

```
sigma = 5;
y = normrnd(0,sigma,100,1);
m = jackknife(@var, y, 1);
n = length(y);
bias = -sigma^2 / n % known bias formula
jbias = (n - 1)*(mean(m)-var(y,1)) % jackknife bias estimate

bias =
    -0.2500

jbias =
    -0.3378
```

See Also

`bootstrp` | `random` | `randsample` | `hist` | `ksdensity`

Tutorials

- “Jackknife” on page 3-19

Purpose

Jarque-Bera test

Syntax

```
h = jbtest(x)
h = jbtest(x,alpha)
[h,p] = jbtest(...)
[h,p,jbstat] = jbtest(...)
[h,p,jbstat,critval] = jbtest(...)
[h,p,...] = jbtest(x,alpha,mctol)
```

Description

`h = jbtest(x)` performs a Jarque-Bera test of the null hypothesis that the sample in vector `x` comes from a normal distribution with unknown mean and variance, against the alternative that it does not come from a normal distribution. The test is specifically designed for alternatives in “Generating Data Using the Pearson System” on page 6-26 of distributions. The test returns the value `h = 1` if it rejects the null hypothesis at the 5% significance level, and `h = 0` if it cannot. The test treats NaN values in `x` as missing values, and ignores them.

The Jarque-Bera test is a two-sided goodness-of-fit test suitable when a fully-specified null distribution is unknown and its parameters must be estimated. The test statistic is

$$JB = \frac{n}{6} \left(s^2 + \frac{(k-3)^2}{4} \right)$$

where n is the sample size, s is the sample skewness, and k is the sample kurtosis. For large sample sizes, the test statistic has a chi-square distribution with two degrees of freedom.

Jarque-Bera tests often use the chi-square distribution to estimate critical values for large samples, deferring to the Lilliefors test (see `lillietest`) for small samples. `jbtest`, by contrast, uses a table of critical values computed using Monte-Carlo simulation for sample sizes less than 2000 and significance levels between 0.001 and 0.50. Critical values for a test are computed by interpolating into the table, using the analytic chi-square approximation only when extrapolating for larger sample sizes.

`h = jbtest(x,alpha)` performs the test at significance level α . α is a scalar in the range [0.001, 0.50]. To perform the test at a significance level outside of this range, use the `mctol` input argument.

`[h,p] = jbtest(...)` returns the p value p , computed using inverse interpolation into the table of critical values. Small values of p cast doubt on the validity of the null hypothesis. `jbtest` warns when p is not found within the tabulated range of [0.001, 0.50], and returns either the smallest or largest tabulated value. In this case, you can use the `mctol` input argument to compute a more accurate p value.

`[h,p,jbstat] = jbtest(...)` returns the test statistic `jbstat`.

`[h,p,jbstat,critval] = jbtest(...)` returns the critical value `critval` for the test. When `jbstat > critval`, the null hypothesis is rejected at significance level α .

`[h,p,...] = jbtest(x,alpha,mctol)` computes a Monte-Carlo approximation for p directly, rather than interpolating into the table of pre-computed values. This is useful when α or p lie outside the range of the table. `jbtest` chooses the number of Monte Carlo replications, `mcreps`, large enough to make the Monte Carlo standard error for p , $\sqrt{p*(1-p)/mcreps}$, less than `mctol`.

Examples

Use `jbtest` to determine if car mileage, in miles per gallon (MPG), follows a normal distribution across different makes of cars:

```
load carbig
[h,p] = jbtest(MPG)
h =
     1
p =
    0.0022
```

The p value is below the default significance level of 5%, and the test rejects the null hypothesis that the distribution is normal.

With a log transformation, the distribution becomes closer to normal, but the p value is still well below 5%:

```
[h,p] = jbstest(log(MPG))  
h =  
    1  
p =  
    0.0078
```

Decreasing the significance level makes it harder to reject the null hypothesis:

```
[h,p] = jbstest(log(MPG),0.0075)  
h =  
    0  
p =  
    0.0078
```

References

- [1] Jarque, C. M., and A. K. Bera. "A test for normality of observations and regression residuals." *International Statistical Review*. Vol. 55, No. 2, 1987, pp. 163–172.
- [2] Deb, P., and M. Sefton. "The Distribution of a Lagrange Multiplier Test of Normality." *Economics Letters*. Vol. 51, 1996, pp. 123–130. This paper proposed a Monte Carlo simulation for determining the distribution of the test statistic. The results of this function are based on an independent Monte Carlo simulation, not the results in this paper.

johnsrnd

Purpose Johnson system random numbers

Syntax

```
r = johnsrnd(quantiles,m,n)
r = johnsrnd(quantiles)
[r,type] = johnsrnd(...)
[r,type,coefs] = johnsrnd(...)
```

Description `r = johnsrnd(quantiles,m,n)` returns an m -by- n matrix of random numbers drawn from the distribution in the Johnson system that satisfies the quantile specification given by `quantiles`. `quantiles` is a four-element vector of quantiles for the desired distribution that correspond to the standard normal quantiles $[-1.5 -0.5 0.5 1.5]$. In other words, you specify a distribution from which to draw random values by designating quantiles that correspond to the cumulative probabilities $[0.067 0.309 0.691 0.933]$. `quantiles` may also be a 2-by-4 matrix whose first row contains four standard normal quantiles, and whose second row contains the corresponding quantiles of the desired distribution. The standard normal quantiles must be spaced evenly.

Note Because `r` is a random sample, its sample quantiles typically differ somewhat from the specified distribution quantiles.

`r = johnsrnd(quantiles)` returns a scalar value.

`r = johnsrnd(quantiles,m,n,...)` or `r = johnsrnd(quantiles,[m,n,...])` returns an m -by- n -by-... array.

`[r,type] = johnsrnd(...)` returns the type of the specified distribution within the Johnson system. `type` is 'SN', 'SL', 'SB', or 'SU'. Set `m` and `n` to zero to identify the distribution type without generating any random values.

The four distribution types in the Johnson system correspond to the following transformations of a normal random variate:

- 'SN' — Identity transformation (normal distribution)

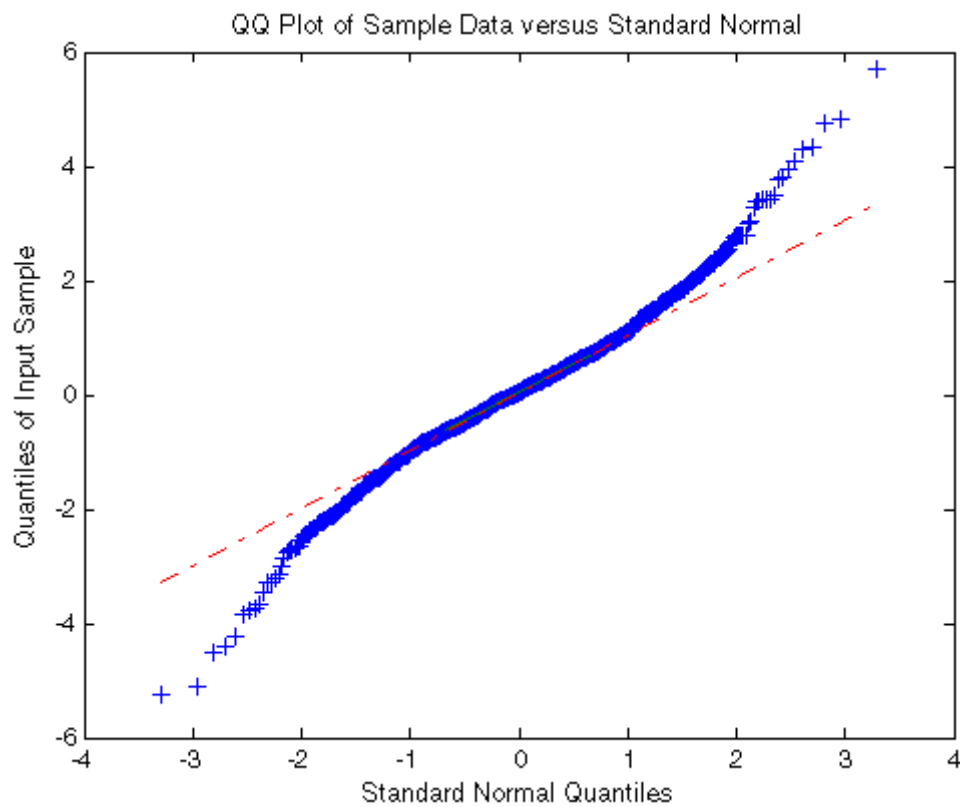
- 'SL' — Exponential transformation (lognormal distribution)
- 'SB' — Logistic transformation (bounded)
- 'SU' — Hyperbolic sine transformation (unbounded)

`[r,type,coefs] = johnsrnd(...)` returns coefficients `coefs` of the transformation that defines the distribution. `coefs` is `[gamma, eta, epsilon, lambda]`. If `z` is a standard normal random variable and `h` is one of the transformations defined above, $r = \lambda * h((z - \text{gamma}) / \text{eta}) + \text{epsilon}$ is a random variate from the distribution type corresponding to `h`.

Examples

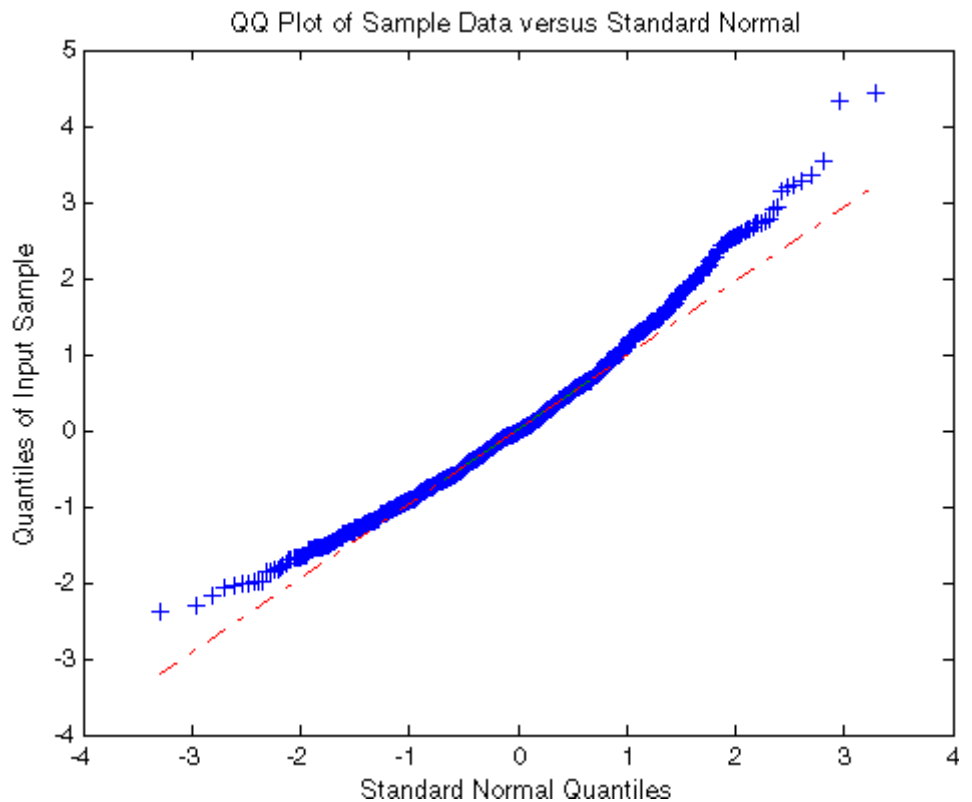
Generate random values with longer tails than a standard normal:

```
r = johnsrnd([-1.7 -.5 .5 1.7],1000,1);  
qqplot(r);
```



Generate random values skewed to the right:

```
r = johnsrnd([-1.3 -.5 .5 1.7],1000,1);  
qqplot(r);
```

Generate random values that match some sample data well in the right-hand tail:

```
load carbig;
qnorm = [.5 1 1.5 2];
q = quantile(Acceleration, normcdf(qnorm));
r = johnsrnd([qnorm;q],1000,1);
[q;q;quantile(r,normcdf(qnorm))]
ans =
    16.7000    18.2086    19.5376    21.7263
    16.8190    18.2474    19.4492    22.4156
```

Determine the distribution type and the coefficients:

```
[r,type,coefs] = johnsrnd([qnorm;q],0)
r =
     []
type =
     SU
coefs =
     1.0920     0.5829    18.4382     1.4494
```

See Also

random | pearsrnd

How To

- “Johnson System” on page B-61

Purpose

Merge observations

Syntax

```
C = join(A,B)
C = join(A,B,keys)
C = join(A,B,param1,va11,param2,va12,...)
[C,IB] = join(...)
C = join(A,B,'Type',TYPE,...)
C = join(A,B,'Type',TYPE,'MergeKeys',true,...)
[C,IA,IB] = join(A,B,'Type',TYPE,...)
```

Description

`C = join(A,B)` creates a dataset array `C` by merging observations from the two dataset arrays `A` and `B`. `join` performs the merge by first finding *key variables*, that is, pairs of dataset variables, one in `A` and one in `B`, that share the same name. Each observation in `B` must contain a unique combination of values in the key variables, and must contain all combinations of values that are present in the keys from `A`. `join` then uses these key variables to define a many-to-one correspondence between observations in `A` and those in `B`. `join` uses this correspondence to replicate the observations in `B` and combine them with the observations in `A` to create `C`.

`C = join(A,B,keys)` performs the merge using the variables specified by `keys` as the key variables in both `A` and `B`. `keys` is a positive integer, a vector of positive integers, a variable name, a cell array of variable names, or a logical vector.

`C` contains one observation for each observation in `A`. Variables in `C` include all of the variables from `A`, as well as one variable corresponding to each variable in `B` (except for the keys from `B`). If `A` and `B` contain variables with identical names, `join` adds the suffix `'_left'` and `'_right'` to the corresponding variables in `C`.

`C = join(A,B,param1,va11,param2,va12,...)` specifies optional parameter name/value pairs to control how the dataset variables in `A` and `B` are used in the merge. Parameters are:

- `'Keys'` — Specifies the variables to use as keys in both `A` and `B`.
- `'LeftKeys'` — Specifies the variables to use as keys in `A`.

dataset.join

- 'RightKeys' — Specifies the variables to use as keys in B.

You may provide either the 'Keys' parameter, or both the 'LeftKeys' and 'RightKeys' parameters. The value for these parameters is a positive integer, a vector of positive integers, a variable name, a cell array containing variable names, or a logical vector. 'LeftKeys' or 'RightKeys' must both specify the same number of key variables, and join pairs the left and right keys in the order specified.

- 'LeftVars' — Specifies which variables from A to include in C. By default, join includes all variables from A.
- 'RightVars' — Specifies which variables from B to include in C. By default, join includes all variables from B except the key variables.

You can use 'LeftVars' or 'RightVars' to include or exclude key variables as well as data variables. The value for these parameters is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector.

`[C,IB] = join(...)` returns an index vector `IB`, where `join` constructs `C` by horizontally concatenating `A(:,LeftVars)` and `B(IB,RightVars)`. `join` can also perform more complicated inner and outer join operations that allow a many-to-many correspondence between A and B, and allow unmatched observations in either A or B.

`C = join(A,B,'Type',TYPE,...)` performs the join operation specified by `TYPE`. `TYPE` is one of 'inner', 'leftouter', 'rightouter', 'fullouter', or 'outer' (which is a synonym for 'fullouter'). For an inner join, `C` only contains observations corresponding to a combination of key values that occurred in both A and B. For a left (or right) outer join, `C` also contains observations corresponding to keys in A (or B) that did not match any in B (or A). Variables in `C` taken from A (or B) contain null values in those observations. A full outer join is equivalent to a left and right outer join. `C` contains variables corresponding to the key variables from both A and B, and `join` sorts the observations in `C` by the key values.

For inner and outer joins, C contains variables corresponding to the key variables from both A and B by default, as well as all the remaining variables. join sorts the observations in the result C by the key values.

`C = join(A,B, 'Type', TYPE, 'MergeKeys', true, ...)` includes a single variable in C for each key variable pair from A and B, rather than including two separate variables. For outer joins, join creates the single variable by merging the key values from A and B, taking values from A where a corresponding observation exists in A, and from B otherwise. Setting the 'MergeKeys' parameter to true overrides inclusion or exclusion of any key variables specified via the 'LeftVars' or 'RightVars' parameter. Setting the 'MergeKeys' parameter to false is equivalent to not passing in the 'MergeKeys' parameter.

`[C, IA, IB] = join(A,B, 'Type', TYPE, ...)` returns index vectors IA and IB indicating the correspondence between observations in C and those in A and B. For an inner join, join constructs C by horizontally concatenating `A(IA, LeftVars)` and `B(IB, RightVars)`. For an outer join, IA or IB may also contain zeros, indicating the observations in C that do not correspond to observations in A or B, respectively.

Examples

Create a dataset array from Fisher's iris data:

```
load fisheriris
NumObs = size(meas,1);
NameObs = strcat({'Obs'}, num2str((1:NumObs)', '%-d'));
iris = dataset({nominal(species), 'species'}, ...
               {meas, 'SL', 'SW', 'PL', 'PW'}, ...
               'ObsNames', NameObs);
```

Create a separate dataset array with the diploid chromosome counts for each species of iris:

```
snames = nominal({'setosa'; 'versicolor'; 'virginica'});
CC = dataset({snames, 'species'}, {[38;108;70], 'cc'})
CC =
    species      cc
```

dataset.join

```
setosa      38
versicolor 108
virginica   70
```

Broadcast the data in CC to the rows of iris using the key variable species in each dataset:

```
iris2 = join(iris,CC);
iris2([1 2 51 52 101 102],:)
ans =
```

	species	SL	SW	PL	PW	cc
Obs1	setosa	5.1	3.5	1.4	0.2	38
Obs2	setosa	4.9	3	1.4	0.2	38
Obs51	versicolor	7	3.2	4.7	1.4	108
Obs52	versicolor	6.4	3.2	4.5	1.5	108
Obs101	virginica	6.3	3.3	6	2.5	70
Obs102	virginica	5.8	2.7	5.1	1.9	70

Create two datasets and join them using the 'MergeKeys' flag:

```
% Create two data sets that both contain the key variable
% 'Key1'. The two arrays contain observations with common
% values of Key1, but each array also contains observations
% with values of Key1 not present in the other.
a = dataset({'a' 'b' 'c' 'e' 'h'},[1 2 3 11 17]',...
    'VarNames',{'Key1' 'Var1'})
b = dataset({'a' 'b' 'd' 'e'},[4 5 6 7]',...
    'VarNames',{'Key1' 'Var2'})

% Combine a and b with an outer join, which matches up
% observations with common key values, but also retains
% observations whose key values don't have a match.
% Keep the key values as separate variables in the result.
couter = join(a,b,'key','Key1','Type','outer')
```

```
% Join a and b, merging the key values as a single variable  
% in the result.
```

```
coutermerge = join(a,b,'key','Key1','Type','outer',...  
  'MergeKeys',true)
```

```
% Join a and b, retaining only observations whose key  
% values match.
```

```
cinner = join(a,b,'key','Key1','Type','inner',...  
  'MergeKeys',true)
```

```
a =
```

Key1	Var1
'a'	1
'b'	2
'c'	3
'e'	11
'h'	17

```
b =
```

Key1	Var2
'a'	4
'b'	5
'd'	6
'e'	7

```
couter =
```

Key1_left	Var1	Key1_right	Var2
'a'	1	'a'	4
'b'	2	'b'	5
'c'	3	' '	NaN
' '	NaN	'd'	6
'e'	11	'e'	7

dataset.join

```
'h'          17      ''          NaN
```

```
coutermerge =
```

Key1	Var1	Var2
'a'	1	4
'b'	2	5
'c'	3	NaN
'd'	NaN	6
'e'	11	7
'h'	17	NaN

```
cinner =
```

Key1	Var1	Var2
'a'	1	4
'b'	2	5
'e'	11	7

See Also

```
sortrows
```


Superclasses NeighborSearcher

Purpose Nearest neighbors search using *kd*-tree

Description A KDTreeSearcher object represents *k*NN (*k*-nearest neighbor) search using a *kd*-tree. Search objects store information about the data used, the distance metric and parameters, and the maximal number of data points in each leaf node. You cannot create this object for sparse input data. The search performance for this object, compared with the ExhaustiveSearcher object, tends to be better for smaller dimensions (10 or fewer) and worse for larger dimensions. For more information on search objects, see “What Are Search Objects?” on page 13-17.

Construction `NS = KDTreeSearcher(X, 'Name', Value)` constructs a *kd*-tree based on *X* and saves the information in a KDTreeSearcher object where rows of *X* correspond to observations and columns correspond to variables. You can use this tree to find neighbors in *X* nearest to the query points. See the following section for optional name/value pairs.

`NS = createns(X, 'NSMethod', 'kdtree', 'Name', Value)` creates a *kd*-tree based on *X* using `createns` and saves the information in a KDTreeSearcher object where rows of *X* correspond to observations and columns correspond to variables. You can use this tree to find neighbors in *X* nearest to the query points. See the following section for optional name/value pairs.

Name-Value Pair Arguments

KDTreeSearcher and createns accept one or more of the following optional name/value pairs as input:

Distance

A string specifying the default distance metric used when you call the `knnsearch` method.

- 'euclidean' — Euclidean distance (default).
- 'cityblock' — City block distance.

KDTreeSearcher

- 'chebychev' — Chebychev distance (maximum coordinate difference).
- 'minkowski' — Minkowski distance.

For more information on these distance metrics, see “Distance Metrics” on page 13-9.

P

A positive scalar indicating the exponent of the Minkowski distance. This parameter is only valid when `Distance` is 'minkowski'. Default is 2.

BucketSize

A positive integer, indicating the maximum number of data points in each leaf node of the *kd*-tree. Default is 50.

Properties

X

A matrix used to create the object

Distance

A string specifying a built-in distance metric that you provide when you create the object. This property is the default distance metric used when you call the `knsearch` method to find nearest neighbors for future query points.

DistParameter

Specifies the additional parameter for the chosen distance metric. The value is:

- If 'Distance' is 'minkowski': A positive scalar indicating the exponent of the Minkowski distance.
- Otherwise: Empty.

Methods

<code>knnsearch</code>	Find k -nearest neighbors using KDTreeSearcher object
<code>rangesearch</code>	Find all neighbors within specified distance using object

Examples

Create a KDTreeSearcher object using the constructor:

```
load fisheriris
x = meas(:,3:4);
kdtreeobj = KDTreeSearcher(x,'distance','minkowski')

kdtreeobj =

    KDTreeSearcher

    Properties:
        BucketSize: 50
                X: [150x2 double]
        Distance: 'minkowski'
        DistParameter: 2
```

Create a KDTreeSearcher object using `createns`:

```
load fisheriris
x = meas(:,3:4);
kdtreeobj = createns(x,'NsMethod','kdtree',...
    'distance','minkowski')

kdtreeobj =

    KDTreeSearcher

    Properties:
        BucketSize: 50
```

KDTreeSearcher

```
X: [150x2 double]
Distance: 'minkowski'
DistParameter: 2
```

For more in-depth examples using the `knnsearch` method, see the method reference page or see “Example: Classifying Query Data Using `knnsearch`” on page 13-18.

References

[1] Friedman, J. H., Bentely, J., and Finkel, R. A. (1977). *An Algorithm for Finding Best Matches in Logarithmic Expected Time*, ACM Transactions on Mathematical Software 3, 209.

See Also

`createns` | `ExhaustiveSearcher` | `NeighborSearcher`

How To

- “*k*-Nearest Neighbor Search and Radius Search” on page 13-12

ProbDistKernel.Kernel property

Purpose Read-only string specifying name of kernel smoothing function for ProbDistKernel object

Description Kernel is a read-only property of the ProbDistKernel class. Kernel is a string specifying the name of the kernel smoothing function used to create a ProbDistKernel object.

Values

- 'normal'
- 'box'
- 'triangle'
- 'epanechnikov'

Use this information to view and compare the kernel smoothing function used to create distributions.

See Also [ksdensity](#)

ClassificationPartitionedEnsemble.kfoldEdge

Purpose Classification edge for observations not used for training

Syntax
E = kfoldEdge(obj)
E = kfoldEdge(obj,Name,Value)

Description E = kfoldEdge(obj) returns classification edge (average classification margin) obtained by cross-validated classification ensemble obj. For every fold, this method computes classification edge for in-fold observations using an ensemble trained on out-of-fold observations.

E = kfoldEdge(obj,Name,Value) calculates edge with additional options specified by one or more Name,Value pair arguments. You can specify several name-value pair arguments in any order as Name1,Value1, ,NameN,ValueN.

Input Arguments

ens
Object of class ClassificationPartitionedEnsemble. Create ens with fitensemble along with one of the cross-validation options: 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'. Alternatively, create ens from a classification ensemble with crossval.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

folds

Indices of folds ranging from 1 to ens.KFold. Use only these folds for predictions.

Default: 1:ens.KFold

mode

ClassificationPartitionedEnsemble.kfoldEdge

String representing the meaning of the output `edge`:

- 'average' — `edge` is a scalar value, the average over all folds.
- 'individual' — `edge` is a vector of length `ens.KFold` with one element per fold.
- 'cumulative' — `edge` is a vector of length `min(ens.NTrainedPerFold)` in which element `J` is obtained by averaging values across all folds for weak learners `1:J` in each fold.

Default: 'average'

Output Arguments

E

The average classification margin. `E` is a scalar or vector, depending on the setting of the `mode` name-value pair.

Definitions

Edge

The *edge* is the weighted mean value of the classification margin. The weights are the class probabilities in `obj.Prior`.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. `Margin` is a column vector with the same number of rows as in the matrix `obj.X`.

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

ClassificationPartitionedEnsemble.kfoldEdge

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

Examples

Compute the k-fold edge for an ensemble trained on the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
cvens = crossval(ens);
E = kfoldEdge(cvens)
```

```
E =
    3.2078
```

See Also

[kfoldPredict](#) | [kfoldLoss](#) | [kfoldMargin](#) | [kfoldfun](#) | [crossval](#)

ClassificationPartitionedModel.kfoldEdge

Purpose	Classification edge for observations not used for training
Syntax	<pre>E = kfoldEdge(obj) E = kfoldEdge(obj,Name,Value)</pre>
Description	<p><code>E = kfoldEdge(obj)</code> returns classification edge (average classification margin) obtained by cross-validated classification model <code>obj</code>. For every fold, this method computes classification edge for in-fold observations using an ensemble trained on out-of-fold observations.</p> <p><code>E = kfoldEdge(obj,Name,Value)</code> calculates edge with additional options specified by one or more <code>Name,Value</code> pair arguments. You can specify several name-value pair arguments in any order as <code>Name1,Value1, ...,NameN,ValueN</code>.</p>
Input Arguments	<p>obj Object of class <code>ClassificationPartitionedModel</code>.</p> <p>Name-Value Pair Arguments Specify optional comma-separated pairs of <code>Name,Value</code> arguments, where <code>Name</code> is the argument name and <code>Value</code> is the corresponding value. <code>Name</code> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <code>Name1,Value1, ...,NameN,ValueN</code>.</p> <p> folds Indices of folds ranging from 1 to <code>obj.KFold</code>. Use only these folds for predictions. Default: <code>1:obj.KFold</code></p> <p> mode String representing the meaning of the output edge:</p> <ul style="list-style-type: none">• 'average' — edge is a scalar value, the average over all folds.

ClassificationPartitionedModel.kfoldEdge

- 'individual' — edge is a vector of length `obj.KFold` with one element per fold.

Default: 'average'

Output Arguments

E

The average classification margin. `E` is a scalar or vector, depending on the setting of the `mode` name-value pair.

Definitions

Edge

The *edge* is the weighted mean value of the classification *margin*. The weights are the class probabilities in `obj.Prior`. If you supply weights in the `weights` name-value pair, those weights are normalized to sum to the prior probabilities in the respective classes, and are then used to compute the weighted average.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `obj.X`. A high value of margin indicates a more reliable prediction than a low value.

Score (discriminant analysis)

For discriminant analysis, the *score* of a classification is the posterior probability of the classification. For the definition of posterior probability in discriminant analysis, see “Posterior Probability” on page 12-7.

Score (tree)

For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

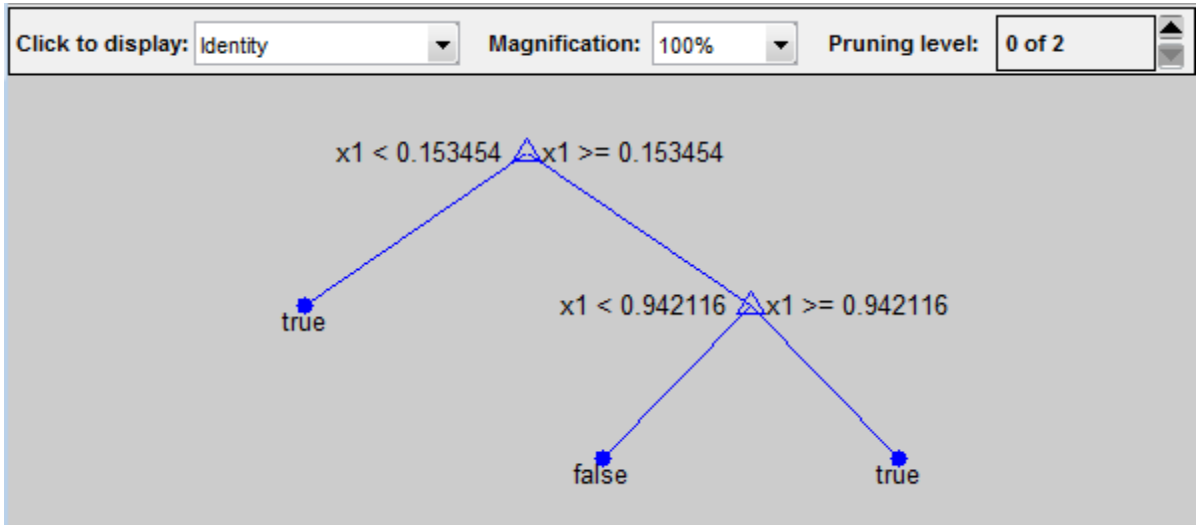
ClassificationPartitionedModel.kfoldEdge

For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```

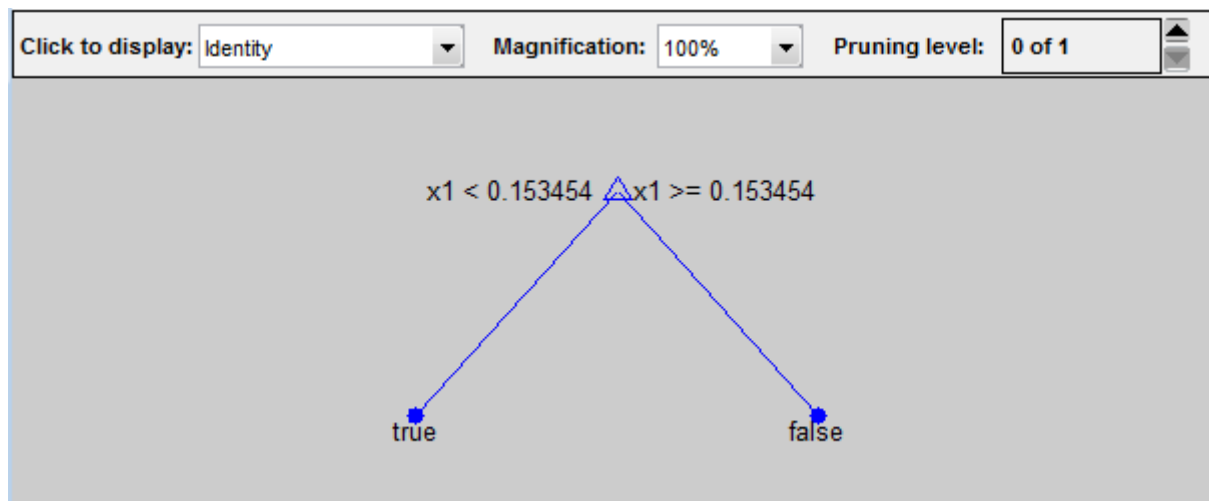


2

Prune the tree:

```
tree1 = prune(tree,'level',1);
view(tree1,'mode','graph')
```

ClassificationPartitionedModel.kfoldEdge



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
    0.9059    0.0941    0.8147  
    0.9059    0.0941    0.9058  
         0    1.0000    0.1270  
    0.9059    0.0941    0.9134  
    0.9059    0.0941    0.6324  
         0    1.0000    0.0975  
    0.9059    0.0941    0.2785
```

0.9059	0.0941	0.5469
0.9059	0.0941	0.9575
0.9059	0.0941	0.9649

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range $(.95, 1)$ instead of the expected 5 observations.

Examples

Compute the k-fold edge for a model trained on the Fisher iris data:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
cvtree = crossval(tree);
E = kfoldEdge(cvtree)
```

```
E =
    0.8711
```

See Also

```
kfoldPredict | kfoldMargin | kfoldLoss | kfoldfun
| crossval | ClassificationPartitionedEnsemble |
ClassificationPartitionedModel
```

ClassificationPartitionedModel.kfoldfun

Purpose Cross validate function

Syntax `vals = kfoldfun(obj,fun)`

Description `vals = kfoldfun(obj,fun)` cross validates the function `fun` by applying `fun` to the data stored in the cross-validated model `obj`. You must pass `fun` as a function handle.

Input Arguments

obj

Object of class `ClassificationPartitionedModel` or `ClassificationPartitionedEnsemble`.

fun

A function handle for a cross-validation function. `fun` has the syntax

```
testvals = fun(CMP,Xtrain,Ytrain,Wtrain,Xtest,Ytest,Wtest)
```

- `CMP` is a compact model stored in one element of the `obj.Trained` property.
- `Xtrain` is the training matrix of predictor values.
- `Ytrain` is the training array of response values.
- `Wtrain` are the training weights for observations.
- `Xtest` and `Ytest` are the test data, with associated weights `Wtest`.
- The returned value `testvals` must have the same size across all folds.

Output Arguments

vals

The arrays of `testvals` output, concatenated vertically over all folds. For example, if `testvals` from every fold is a numeric vector of length `N`, `kfoldfun` returns a `KFold-by-N` numeric matrix with one row per fold.

Examples

Cross validate a classification tree, and obtain the classification error (see `kfoldLoss`):

```
load fisheriris
t = ClassificationTree.fit(meas,species);
rng(0,'twister') % for reproducibility
cv = crossval(t);
L = kfoldLoss(cv)
```

```
L =
    0.0467
```

Examine the result when the error of misclassifying a flower as 'versicolor' is 10, and any other error is 1:

- 1 Write a function file that gives a cost of 1 for misclassification, but 10 for misclassifying a flower as `versicolor`.

```
function averageCost = noversicolor(CMP,Xtrain,Ytrain,Wtrain,Xtest,Ytest,Wtest)

Ypredict = predict(CMP,Xtest);
misclassified = not(strcmp(Ypredict,Ytest)); % different result
classifiedAsVersicolor = strcmp(Ypredict,'versicolor'); % index of bad decisions
cost = sum(misclassified) + ...
    9*sum(misclassified & classifiedAsVersicolor); % total differences
averageCost = cost/numel(Ytest); % average error
```

- 2 Save the file as `noversicolor.m` on your MATLAB path.
- 3 Compute the mean misclassification error with the `noversicolor` cost:

```
mean(kfoldfun(cv,@noversicolor))

ans =
    0.1667
```

ClassificationPartitionedModel.kfoldfun

See Also

`ClassificationPartitionedModel` | `kfoldPredict` | `kfoldEdge` |
`kfoldMargin` | `kfoldLoss` | `crossval`

RegressionPartitionedModel.kfoldfun

Purpose

Cross validate function

Syntax

```
vals = kfoldfun(obj,fun)
```

Description

`vals = kfoldfun(obj,fun)` cross validates the function `fun` by applying `fun` to the data stored in the cross-validated model `obj`. You must pass `fun` as a function handle.

Input Arguments

obj

Object of class `RegressionPartitionedModel` or `RegressionPartitionedEnsemble`. Create `obj` with `RegressionTree.fit` or `fitensemble` along with one of the cross-validation options: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Alternatively, create `obj` from a regression tree or regression ensemble with `crossval`.

fun

A function handle for a cross-validation function. `fun` has the syntax

```
testvals = fun(CMP,Xtrain,Ytrain,Wtrain,Xtest,Ytest,Wtest)
```

- `CMP` is a compact model stored in one element of the `obj.Trained` property.
- `Xtrain` is the training matrix of predictor values.
- `Ytrain` is the training array of response values.
- `Wtrain` are the training weights for observations.
- `Xtest` and `Ytest` are the test data, with associated weights `Wtest`.
- The returned value `testvals` must have the same size across all folds.

RegressionPartitionedModel.kfoldfun

Output Arguments

vals

The arrays of testvals output, concatenated vertically over all folds. For example, if testvals from every fold is a numeric vector of length N, kfoldfun returns a KFold-by-N numeric matrix with one row per fold.

Examples

Cross validate a regression tree, and obtain the mean squared error (see kfoldLoss):

```
load imports-85
t = RegressionTree.fit(X(:,[4 5]),X(:,16),...
    'predictorname',{'length' 'width'},...
    'response', 'price');
cv = crossval(t);
L = kfoldLoss(cv)
```

```
L =
    1.5489e+007
```

Examine the result of simple averaging of responses instead of using predictions:

```
f = @(cmp,Xtrain,Ytrain,Wtrain,Xtest,Ytest,Wtest)...
    mean((Ytest-mean(Ytrain)).^2)
mean(kfoldfun(cv,f))

ans =
    6.3497e+007
```

See Also

RegressionPartitionedEnsemble | kfoldPredict | kfoldLoss | RegressionPartitionedModel | crossval

ClassificationPartitionedEnsemble.kfoldLoss

Purpose

Classification loss for observations not used for training

Syntax

```
L = kfoldLoss(ens)
L = kfoldLoss(ens,Name,Value)
```

Description

`L = kfoldLoss(ens)` returns loss obtained by cross-validated classification model `ens`. For every fold, this method computes classification loss for in-fold observations using a model trained on out-of-fold observations.

`L = kfoldLoss(ens,Name,Value)` calculates loss with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

ens

Object of class `ClassificationPartitionedEnsemble`. Create `ens` with `fitensemble` along with one of the cross-validation options: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Alternatively, create `ens` from a classification ensemble with `crossval`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

folders

Indices of folds ranging from 1 to `ens.KFold`. Use only these folds for predictions.

Default: `1:ens.KFold`

lossfun

ClassificationPartitionedEnsemble.kfoldLoss

Function handle or string representing a loss function. Built-in loss functions:

- 'binodeviance' — See “Loss Functions” on page 20-1042
- 'classiferror' — Fraction of misclassified data
- 'exponential' — See “Loss Functions” on page 20-1042

You can write your own loss function in the syntax described in “Loss Functions” on page 20-1042.

Default: 'classiferror'

mode

A string for determining the output of `kfoldLoss`:

- 'average' — `L` is a scalar, the loss averaged over all folds.
- 'individual' — `L` is a vector of length `ens.KFold`, where each entry is the loss for a fold.
- 'cumulative' — `L` is a vector in which element `J` is obtained by using learners `1:J` from the input list of learners.

Default: 'average'

Output Arguments

L

Loss, by default the fraction of misclassified data. `L` can be a vector, and can mean different things, depending on the name-value pair settings.

Definitions

Loss Functions

The built-in loss functions are:

ClassificationPartitionedEnsemble.kfoldLoss

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'classiferror' — Fraction of misclassified data, weighted by w .
- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

To write your own loss function, create a function file of the form

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of `ens.X`.
- K is the number of classes in `ens`, represented in `ens.ClassNames`.
- C is an N-by-K logical matrix, with one true per row for the true class. The index for each class is its position in `tree.ClassNames`.
- S is an N-by-K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the score output from `predict`.
- W is a numeric vector with N elements, the observation weights.
- COST is a K-by-K numeric matrix of misclassification costs. The default 'classiferror' gives a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

ClassificationPartitionedEnsemble.kfoldLoss

Examples

Find the average cross-validated classification error for an ensemble model of the ionosphere data:

```
load ionosphere
ens = fitensemble(X,Y,'AdaBoostM1',100,'Tree');
cvens = crossval(ens);
L = kfoldLoss(cvens)
```

```
L =
    0.0826
```

See Also

[kfoldPredict](#) | [kfoldEdge](#) | [kfoldMargin](#) | [kfoldfun](#) | [crossval](#)

ClassificationPartitionedModel.kfoldLoss

Purpose

Classification loss for observations not used for training

Syntax

```
L = kfoldLoss(obj)
L = kfoldLoss(obj,Name,Value)
```

Description

`L = kfoldLoss(obj)` returns loss obtained by cross-validated classification model `obj`. For every fold, this method computes classification loss for in-fold observations using a model trained on out-of-fold observations.

`L = kfoldLoss(obj,Name,Value)` calculates loss with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

obj

Object of class `ClassificationPartitionedModel`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

folds

Indices of folds ranging from 1 to `obj.KFold`. Use only these folds for predictions.

Default: `1:obj.KFold`

lossfun

Function handle or string representing a loss function. Built-in loss functions:

ClassificationPartitionedModel.kfoldLoss

- 'binodeviance' — See “Loss Functions” on page 20-1047.
- 'classiferror' — Fraction of misclassified observations. See “Loss Functions” on page 20-1047.
- 'exponential' — See “Loss Functions” on page 20-1047.
- 'mincost' — Smallest misclassification cost as given by the `obj.Cost` matrix. See “Loss Functions” on page 20-1047.

You can write your own loss function in the syntax described in “Loss Functions” on page 20-1047.

Default: 'mincost'

mode

A string for determining the output of `kfoldLoss`:

- 'average' — L is a scalar, the loss averaged over all folds.
- 'individual' — L is a vector of length `obj.KFold`, where each entry is the loss for a fold.

Default: 'average'

Output Arguments

L

Loss, by default the fraction of misclassified data. L can be a vector, and can mean different things, depending on the name-value pair settings.

Definitions

Classification Error

The default classification error is the fraction of the data X that `obj` misclassifies, where Y are the true classifications.

Weighted classification error is the sum of weight i times the Boolean value that is 1 when `obj` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

- 'classiferror' — Predict the label with the largest posterior probability. The loss is then the fraction of misclassified observations.
- 'mincost' — Predict the label with the smallest expected misclassification cost, with expectation taken over the posterior probability, and cost as given by the Cost property of the classifier (a matrix). The loss is then the true misclassification cost averaged over the observations.

To write your own loss function, create a function file in this form:

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of X.
- K is the number of classes in the classifier, represented in the ClassNames property.
- C is an N-by-K logical matrix, with one true per row for the true class. The index for each class is its position in the ClassNames property.
- S is an N-by-K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from predict.

ClassificationPartitionedModel.kfoldLoss

- W is a numeric vector with N elements, the observation weights. If you pass W , the elements are normalized to sum to the prior probabilities in the respective classes.
- $COST$ is a K -by- K numeric matrix of misclassification costs. For example, you can use $COST = \text{ones}(K) - \text{eye}(K)$, which means a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

Examples

Find the average cross-validated classification error for a model of the ionosphere data:

```
load ionosphere
tree = ClassificationTree.fit(X,Y);
cvtree = crossval(tree);
L = kfoldLoss(cvtree)
```

```
L =
    0.1197
```

See Also

[ClassificationPartitionedModel](#) | [kfoldPredict](#) | [kfoldEdge](#) | [kfoldMargin](#) | [kfoldfun](#) | [crossval](#)

How To

- “Examine the Quality of a KNN Classifier” on page 13-26

RegressionPartitionedEnsemble.kfoldLoss

Purpose

Cross-validation loss of partitioned regression ensemble

Syntax

```
L = kfoldLoss(cvens)
L = kfoldLoss(cvens,Name,Value)
```

Description

`L = kfoldLoss(cvens)` returns the cross-validation loss of `cvens`.

`L = kfoldLoss(cvens,Name,Value)` returns cross-validation loss with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

cvens

Object of class `RegressionPartitionedEnsemble`. Create `obj` with `fitensemble` along with one of the cross-validation options: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Alternatively, create `obj` from a regression ensemble with `crossval`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

folds

Indices of folds ranging from 1 to `cvens.KFold`. Use only these folds for predictions.

Default: `1:cvens.KFold`

lossfun

RegressionPartitionedEnsemble.kfoldLoss

Function handle for loss function, or the string 'mse', meaning mean squared error. If you pass a function handle `fun`, `loss` calls it as

```
fun(Y,Yfit,W)
```

where `Y`, `Yfit`, and `W` are numeric vectors of the same length.

- `Y` is the observed response.
- `Yfit` is the predicted response.
- `W` is the observation weights.

The returned value `fun(Y,Yfit,W)` should be a scalar.

Default: 'mse'

mode

String representing the meaning of the output `L`:

- 'ensemble' — `L` is a scalar value, the loss for the entire ensemble.
- 'individual' — `L` is a vector with one element per trained learner.
- 'cumulative' — `L` is a vector in which element `J` is obtained by using learners `1:J` from the input list of learners.

Default: 'ensemble'

Output Arguments

L

The loss (mean squared error) between the observations in a fold when compared against predictions made with an ensemble trained on the out-of-fold data. `L` can be a vector, and can mean different things, depending on the name-value pair settings.

Examples

Find the cross-validation loss for a regression ensemble of the carsmall data:

```
load carsmall
X = [Displacement Horsepower Weight];
rens = fitensemble(X,MPG,'LSboost',100,'Tree');
cvrens = crossval(rens);
L = kfoldLoss(cvrens)
```

```
L =
    25.6935
```

See Also

[RegressionPartitionedEnsemble](#) | [loss](#) | [kfoldPredict](#)

RegressionPartitionedModel.kfoldLoss

Purpose Cross-validation loss of partitioned regression model

Syntax
L = kfoldLoss(cvmodel)
L = kfoldLoss(cvmodel,Name,Value)

Description L = kfoldLoss(cvmodel) returns the cross-validation loss of cvmodel.
L = kfoldLoss(cvmodel,Name,Value) returns cross-validation loss with additional options specified by one or more Name,Value pair arguments. You can specify several name-value pair arguments in any order as Name1,Value1, ,NameN,ValueN.

Input Arguments

cvmodel
Object of class RegressionPartitionedModel. Create obj with RegressionTree.fit along with one of the cross-validation options: 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'. Alternatively, create obj from a regression tree with crossval.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1, . . . ,NameN,ValueN.

folds

Indices of folds ranging from 1 to Obj.KFold. Use only these folds for predictions.

Default: 1:Obj.KFold

lossfun

RegressionPartitionedModel.kfoldLoss

Function handle for loss function, or the string 'mse', meaning mean squared error. If you pass a function handle `fun`, `kfoldLoss` calls it as

```
fun(Y,Yfit,W)
```

where `Y`, `Yfit`, and `W` are numeric vectors of the same length.

- `Y` is the observed response.
- `Yfit` is the predicted response.
- `W` is the observation weights.

The returned value `fun(Y,Yfit,W)` should be a scalar.

Default: 'mse'

mode

One of the following strings:

- 'average' — `L` is the average loss over all folds.
- 'individual' — `L` is a vector of the individual losses of in-fold observations trained on out-of-fold data.

Default: 'average'

Output Arguments

L

The loss (mean squared error) between the observations in a fold when compared against predictions made with a tree trained on the out-of-fold data. If `mode` is 'individual', `L` is a vector of the losses. If `mode` is 'average', `L` is the average loss.

Examples

Construct a partitioned regression model, and examine the cross-validation losses for the folds:

```
load carsmall
```

RegressionPartitionedModel.kfoldLoss

```
XX = [Cylinders Displacement Horsepower Weight];
YY = MPG;
cvmodel = RegressionTree.fit(XX,YY,'crossval','on');
L = kfoldLoss(cvmodel,'mode','individual')
```

```
L =
    44.9635
    11.8525
    18.2046
     9.2965
    29.4329
    54.8659
    24.6446
     8.2085
    19.7593
    16.7394
```

Alternatives

You can avoid constructing a cross-validated tree model by calling `cvLoss` instead of `kfoldLoss`. The cross-validated tree can save time if you are going to examine it more than once.

See Also

`loss` | `kfoldPredict`

ClassificationPartitionedModel.kfoldMargin

Purpose	Classification margins for observations not used for training
Syntax	<code>M = kfoldMargin(obj)</code>
Description	<code>M = kfoldMargin(obj)</code> returns classification margins obtained by cross-validated classification model <code>obj</code> . For every fold, this method computes classification margins for in-fold observations using a model trained on out-of-fold observations.
Input Arguments	obj A partitioned classification model of type <code>ClassificationPartitionedModel</code> or <code>ClassificationPartitionedEnsemble</code> .
Output Arguments	M The classification margin.
Definitions	Margin The classification <i>margin</i> is the difference between the classification <i>score</i> for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix <code>Obj.X</code> . A high value of margin indicates a more reliable prediction than a low value. Score (discriminant analysis) For discriminant analysis, the <i>score</i> of a classification is the posterior probability of the classification. For the definition of posterior probability in discriminant analysis, see “Posterior Probability” on page 12-7. Score (ensemble) For ensembles, a classification <i>score</i> represents the confidence of a classification into a class. The higher the score, the higher the confidence.

ClassificationPartitionedModel.kfoldMargin

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

Score (tree)

For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

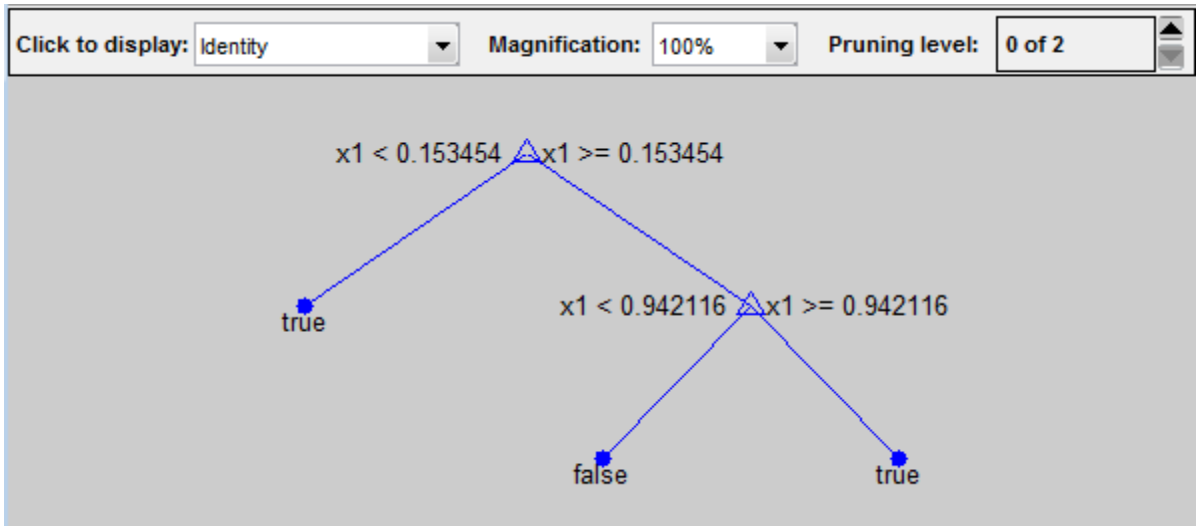
For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```

ClassificationPartitionedModel.kfoldMargin

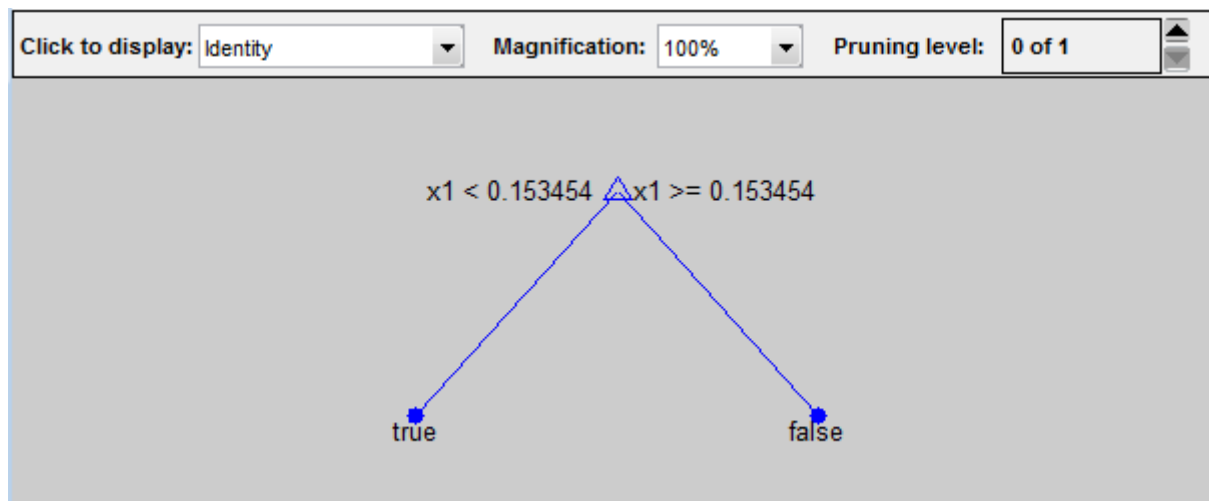


2

Prune the tree:

```
tree1 = prune(tree, 'level', 1);  
view(tree1, 'mode', 'graph')
```

ClassificationPartitionedModel.kfoldMargin



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
    0.9059    0.0941    0.8147  
    0.9059    0.0941    0.9058  
         0    1.0000    0.1270  
    0.9059    0.0941    0.9134  
    0.9059    0.0941    0.6324  
         0    1.0000    0.0975  
    0.9059    0.0941    0.2785
```

ClassificationPartitionedModel.kfoldMargin

```
0.9059    0.0941    0.5469
0.9059    0.0941    0.9575
0.9059    0.0941    0.9649
```

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range (.95, 1) instead of the expected 5 observations.

Examples

Find the k-fold margins for an ensemble that classifies the ionosphere data:

```
load ionosphere
ens = fitensemble(X,Y,'AdaBoostM1',100,'Tree');
cvens = crossval(ens);
M = kfoldMargin(cvens);
[min\(M\) mean\(M\) max\(M\)]

ans =
    -7.6394     7.3469    22.4833
```

See Also

[ClassificationPartitionedModel](#) | [kfoldPredict](#) | [kfoldEdge](#) | [kfoldLoss](#) | [kfoldfun](#) | [crossval](#)

ClassificationPartitionedModel.kfoldPredict

Purpose Predict response for observations not used for training

Syntax

```
label = kfoldPredict(obj)
[label,score] = kfoldPredict(obj)
[label,score,cost] = kfoldPredict(obj)
```

Description `label = kfoldPredict(obj)` returns class labels predicted by `obj`, a cross-validated classification. For every fold, `kfoldPredict` predicts class labels for in-fold observations using a model trained on out-of-fold observations.

`[label,score] = kfoldPredict(obj)` returns the predicted classification scores for in-fold observations using a model trained on out-of-fold observations.

`[label,score,cost] = kfoldPredict(obj)` returns misclassification costs.

Input Arguments

obj
Object of class `ClassificationPartitionedModel` or `ClassificationPartitionedEnsemble`.

Output Arguments

label
Vector of class labels of the same type as the response data used in training `obj`. Each entry of `label` corresponds to a predicted class label for the corresponding row of `X`.

score
Numeric matrix of size N-by-K, where N is the number of observations (rows) in `obj.X`, and K is the number of classes (in `obj.ClassNames`). `score(i,j)` represents the confidence that row `i` of `obj.X` is of class `j`. For details, see “Definitions” on page 20-1061.

cost

Numeric matrix of misclassification costs of size N-by-K. $\text{cost}(i, j)$ is the average misclassification cost of predicting that row i of obj.X is of class j .

Definitions

Cost (discriminant analysis)

The *average misclassification cost* is the mean misclassification cost for predictions made by the cross-validated classifiers trained on out-of-fold observations. The matrix of expected costs per observation is defined in “Cost” on page 12-8.

Score (discriminant analysis)

For discriminant analysis, the *score* of a classification is the posterior probability of the classification. For the definition of posterior probability in discriminant analysis, see “Posterior Probability” on page 12-7.

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

Score (tree)

For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

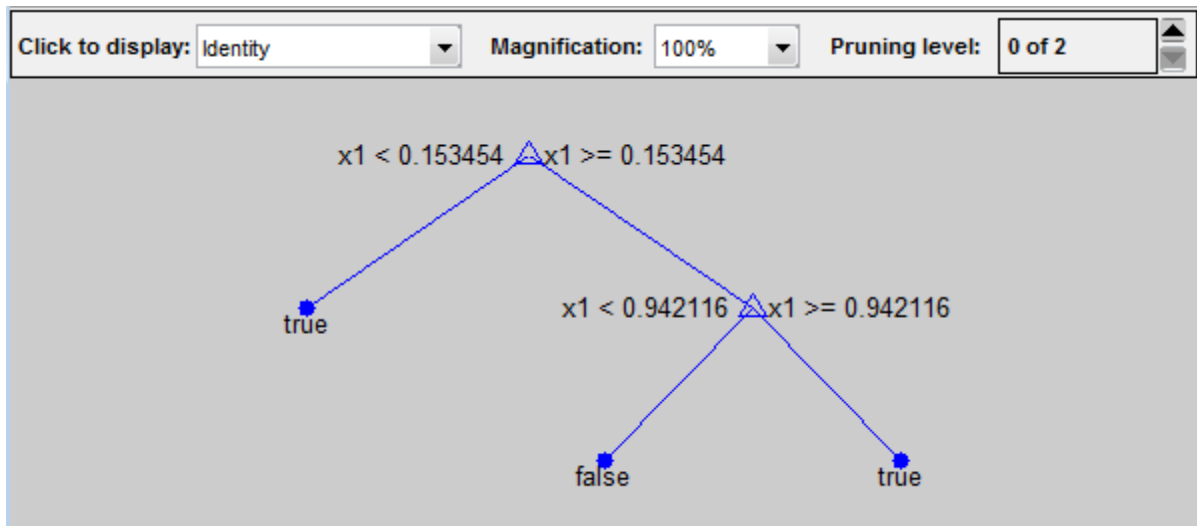
For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

ClassificationPartitionedModel.kfoldPredict

1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```

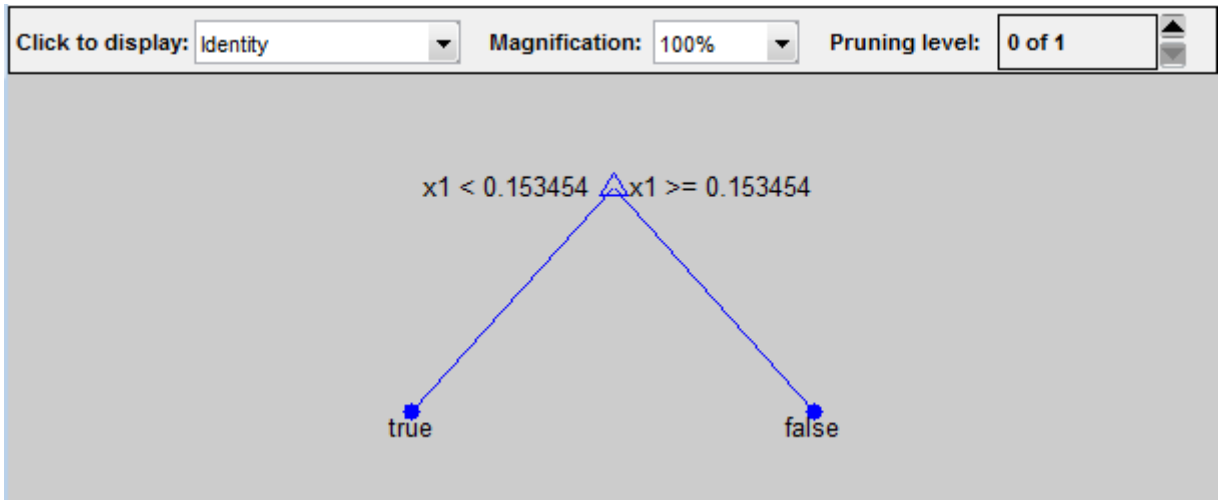


2

Prune the tree:

```
tree1 = prune(tree,'level',1);
view(tree1,'mode','graph')
```


ClassificationPartitionedModel.kfoldPredict



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
    0.9059    0.0941    0.8147  
    0.9059    0.0941    0.9058  
         0    1.0000    0.1270  
    0.9059    0.0941    0.9134  
    0.9059    0.0941    0.6324  
         0    1.0000    0.0975  
    0.9059    0.0941    0.2785
```

ClassificationPartitionedModel.kfoldPredict

```
0.9059    0.0941    0.5469
0.9059    0.0941    0.9575
0.9059    0.0941    0.9649
```

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range (.95, 1) instead of the expected 5 observations.

Examples

Find the cross-validation predictions for a model based on the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
cvens = crossval(ens);
[elabel escore] = kfoldPredict(cvens);
max(escore)
```

```
ans =
    9.3634    8.5624    9.3981
```

```
min(escore)
```

```
ans =
    0.0017    3.7518    0.8911
```

See Also

[ClassificationPartitionedModel](#) | [kfoldEdge](#) | [kfoldMargin](#) | [kfoldLoss](#) | [kfoldfun](#) | [crossval](#)

RegressionPartitionedModel.kfoldPredict

Purpose

Predict response for observations not used for training.

Syntax

```
yfit = kfoldPredict(obj)
```

Description

`yfit = kfoldPredict(obj)` returns the predicted values for the responses of the training data based on `obj`, an object trained on out-of-fold observations.

Input Arguments

obj

Object of class `RegressionPartitionedModel`. Create `obj` with `RegressionTree.fit` or `fitensemble` along with one of the cross-validation options: `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. Alternatively, create `obj` from a regression tree or regression ensemble with `crossval`.

Output Arguments

yfit

A vector of predicted values for the response data based on a model trained on out-of-fold observations.

Examples

Construct a partitioned regression model, and examine the cross-validation loss. The cross-validation loss is the mean squared error between `yfit` and the true response data:

```
load carsmall
XX = [Cylinders Displacement Horsepower Weight];
YY = MPG;
tree = RegressionTree.fit(XX,YY);
cvmodel = crossval(tree);
L = kfoldLoss(cvmodel)

L =
    26.5271

yfit = kfoldPredict(cvmodel);
mean( (yfit - tree.Y).^2 )
```

RegressionPartitionedModel.kfoldPredict

```
ans =  
  26.5271
```

See Also `kfoldLoss`

Purpose

K-means clustering

Syntax

```
IDX = kmeans(X,k)
[IDX,C] = kmeans(X,k)
[IDX,C,sumd] = kmeans(X,k)
[IDX,C,sumd,D] = kmeans(X,k)
[...] = kmeans(...,param1,val1,param2,val2,...)
```

Description

`IDX = kmeans(X,k)` partitions the points in the *n*-by-*p* data matrix *X* into *k* clusters. This iterative partitioning minimizes the sum, over all clusters, of the within-cluster sums of point-to-cluster-centroid distances. Rows of *X* correspond to points, columns correspond to variables. `kmeans` returns an *n*-by-1 vector `IDX` containing the cluster indices of each point. By default, `kmeans` uses squared Euclidean distances. When *X* is a vector, `kmeans` treats it as an *n*-by-1 data matrix, regardless of its orientation.

`[IDX,C] = kmeans(X,k)` returns the *k* cluster centroid locations in the *k*-by-*p* matrix `C`.

`[IDX,C,sumd] = kmeans(X,k)` returns the within-cluster sums of point-to-centroid distances in the 1-by-*k* vector `sumd`.

`[IDX,C,sumd,D] = kmeans(X,k)` returns distances from each point to every centroid in the *n*-by-*k* matrix `D`.

`[...] = kmeans(...,param1,val1,param2,val2,...)` enables you to specify optional parameter/value pairs to control the iterative algorithm used by `kmeans`. Valid parameter strings are listed in the following table.

kmeans

Parameter	Value
'distance'	Distance measure, in p-dimensional space. kmeans minimizes with respect to this parameter. kmeans computes centroid clusters differently for the different supported distance measures.
	'sqEuclidean' Squared Euclidean distance (default). Each centroid is the mean of the points in that cluster.
	'cityblock' Sum of absolute differences, i.e., the L1 distance. Each centroid is the component-wise median of the points in that cluster.
	'cosine' One minus the cosine of the included angle between points (treated as vectors). Each centroid is the mean of the points in that cluster, after normalizing those points to unit Euclidean length.
	'correlation' One minus the sample correlation between points (treated as sequences of values). Each centroid is the component-wise mean of the points in that cluster, after centering and normalizing those points to zero mean and unit standard deviation.
	'Hamming' Percentage of bits that differ (only suitable for binary data). Each centroid is the component-wise median of points in that cluster.

Parameter	Value	
'emptyaction'	Action to take if a cluster loses all its member observations.	
	'error'	Treat an empty cluster as an error (default).
	'drop'	Remove any clusters that become empty. kmeans sets the corresponding return values in C and D to NaN.
	'singleton'	Create a new cluster consisting of the one point furthest from its centroid.
'onlinephase'	Flag indicating whether kmeans should perform an online update phase in addition to a batch update phase. The online phase can be time consuming for large data sets, but guarantees a solution that is a local minimum of the distance criterion, that is, a partition of the data where moving any single point to a different cluster increases the total sum of distances.	
	'on'	Perform online update (default).
	'off'	Do not perform online update.

kmeans

Parameter	Value
'options'	Structure specifying options for the iterative algorithm used to minimize the fitting criteria. Create the options structure with <code>statset</code> . Applicable <code>statset</code> parameters are:
Display	Level of display output. Choices are <code>'off'</code> (default), <code>'iter'</code> , and <code>'final'</code> .
MaxIter	Maximum number of iterations allowed. The default is 100.
UseParallel	If <code>'always'</code> and if a <code>matlabpool</code> of the Parallel Computing Toolbox is open, compute in parallel. If the Parallel Computing Toolbox is not installed, or a <code>matlabpool</code> is not open, computation occurs in serial mode. Default is <code>'never'</code> , meaning serial computation.
UseSubstreams	Set to <code>'always'</code> to compute in parallel in a reproducible fashion. Default is <code>'never'</code> . To compute reproducibly, set <code>Streams</code> to a type allowing substreams: <code>'mlfg6331_64'</code> or <code>'mrg32k3a'</code> .
Streams	A <code>RandStream</code> object or cell array of such objects. If you do not specify <code>Streams</code> , <code>kmeans</code> uses the default stream or streams. If you choose to specify <code>Streams</code> , use a single object except in the case: <ul style="list-style-type: none">You have an open MATLAB pool

Parameter	Value	
	<ul style="list-style-type: none"> • UseParallel is 'always' • UseSubstreams is 'never' <p>In that case, use a cell array the same size as the MATLAB pool. If a MATLAB pool is not open, then Streams must supply a single random number stream.</p>	
'replicates'	Number of times to repeat the clustering, each with a new set of initial cluster centroid positions. kmeans returns the solution with the lowest value for sumd. You can supply 'replicates' implicitly by supplying a 3D array as the value for the 'start' parameter.	
'start'	Method used to choose the initial cluster centroid positions, sometimes known as <i>seeds</i> .	
	'sample'	Select k observations from X at random (default).
	'uniform'	Select k points uniformly at random from the range of X. Not valid with Hamming distance.
	'cluster'	Perform a preliminary clustering phase on a random 10% subsample of X. This preliminary phase is itself initialized using 'sample'.
	Matrix	k-by-p matrix of centroid starting locations. In this case, you can pass in [] for k, and kmeans infers k from the first dimension of the matrix. You can also supply a 3-D array, implying a value for the

kmeans

Parameter	Value
	'replicates' parameter from the array's third dimension.

Algorithms

kmeans uses a two-phase iterative algorithm to minimize the sum of point-to-centroid distances, summed over all k clusters:

- 1** The first phase uses *batch updates*, where each iteration consists of reassigning points to their nearest cluster centroid, all at once, followed by recalculation of cluster centroids. This phase occasionally does not converge to solution that is a local minimum, that is, a partition of the data where moving any single point to a different cluster increases the total sum of distances. This is more likely for small data sets. The batch phase is fast, but potentially only approximates a solution as a starting point for the second phase.
- 2** The second phase uses *online updates*, where points are individually reassigned if doing so will reduce the sum of distances, and cluster centroids are recomputed after each reassignment. Each iteration during the second phase consists of one pass though all the points. The second phase will converge to a local minimum, although there may be other local minima with lower total sum of distances. The problem of finding the global minimum can only be solved in general by an exhaustive (or clever, or lucky) choice of starting points, but using several replicates with random starting points typically results in a solution that is a global minimum.

References

- [1] Seber, G. A. F. *Multivariate Observations*. Hoboken, NJ: John Wiley & Sons, Inc., 1984.
- [2] Spath, H. *Cluster Dissection and Analysis: Theory, FORTRAN Programs, Examples*. Translated by J. Goldschmidt. New York: Halsted Press, 1985.

Examples

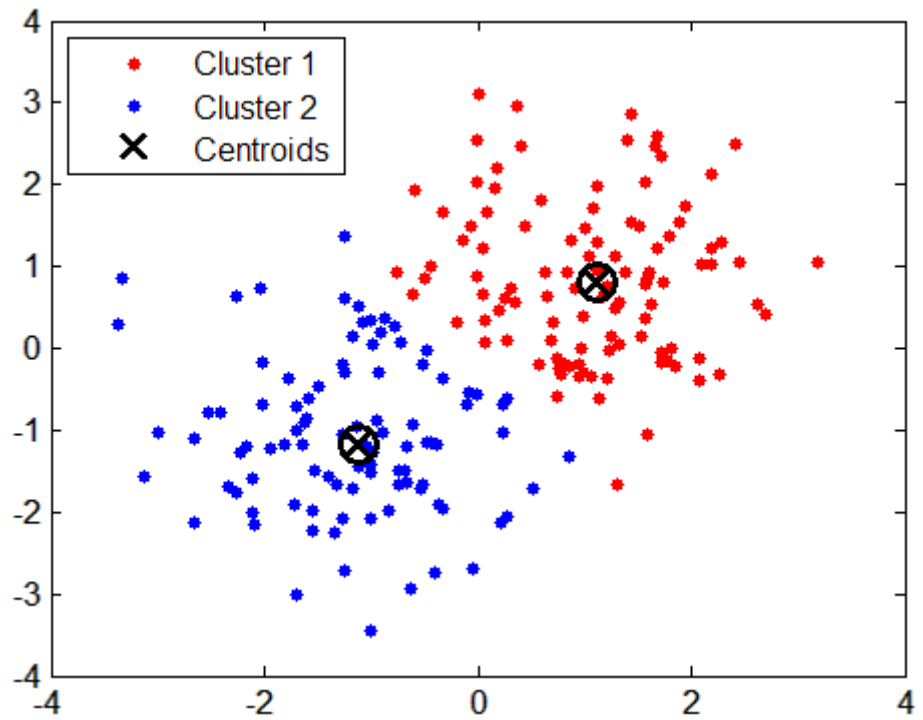
The following creates two clusters from separated random data:

```
X = [randn(100,2)+ones(100,2);...
      randn(100,2)-ones(100,2)];
opts = statset('Display','final');

[idx,ctrs] = kmeans(X,2,...
                   'Distance','city',...
                   'Replicates',5,...
                   'Options',opts);
5 iterations, total sum of distances = 284.671
4 iterations, total sum of distances = 284.671
4 iterations, total sum of distances = 284.671
3 iterations, total sum of distances = 284.671
3 iterations, total sum of distances = 284.671

plot(X(idx==1,1),X(idx==1,2),'r.','MarkerSize',12)
hold on
plot(X(idx==2,1),X(idx==2,2),'b.','MarkerSize',12)
plot(ctrs(:,1),ctrs(:,2),'kx',...
      'MarkerSize',12,'LineWidth',2)
plot(ctrs(:,1),ctrs(:,2),'ko',...
      'MarkerSize',12,'LineWidth',2)
legend('Cluster 1','Cluster 2','Centroids',...
      'Location','NW')
```

kmeans



See Also

[linkage](#) | [clusterdata](#) | [silhouette](#)

Purpose Find k -nearest neighbors using ExhaustiveSearcher object

Syntax

```
IDX = knnsearch(NS,Y)
[IDX,D] = knnsearch(NS,Y)
[IDX,D] = knnsearch(NS,Y,'Name',Value)
```

Description `IDX = knnsearch(NS,Y)` finds the nearest neighbor (closest point) in `NS.X` for each point in `Y`. Rows of `Y` correspond to observations and columns correspond to features. `Y` must have the same number of columns as `NS.X`. `IDX` is a column vector with n_y rows, where n_y is the number of rows in `Y`. Each row in `IDX` contains the index of observation in `NS.X` which has the smallest distance to the corresponding observation in `Y`.

`[IDX,D] = knnsearch(NS,Y)` returns a column vector `D` containing the distances between each observation in `Y` and the corresponding closest observation in `NS.X`. That is, `D(i)` is the distance between `NS.X(IDX(i),:)` and `Y(i,:)`.

`[IDX,D] = knnsearch(NS,Y,'Name',Value)` accepts one or more comma-separated argument name/value pairs. Specify *Name* inside single quotes.

Input Arguments

Name-Value Pair Arguments

K

A positive integer, k , specifying the number of nearest neighbors in `NS.X` for each point in `Y`. Default is 1. `IDX` and `D` are n_y -by- k matrices. `D` sorts the distances in each row in ascending order. Each row in `IDX` contains the indices of the k closest neighbors in `NS.X` corresponding to the k smallest distances in `D`.

IncludeTies

A logical value indicating whether `knnsearch` includes all the neighbors whose distance values are equal to the K th smallest distance. If `IncludeTies` is `true`, `knnsearch` includes all these neighbors. In this case, `IDX` and `D` are n_y -by-1 cell arrays. Each

ExhaustiveSearcher.knnsearch

row in `IDX` and `D` contains a vector with at least `K` numeric numbers. `D` sorts the distances in each vector in ascending order. Each row in `IDX` contains the indices of the closest neighbors corresponding to these smallest distances in `D`.

Default: `false`

Distance

- `'euclidean'` — Euclidean distance (default).
- `'seuclidean'` — Standardized Euclidean distance. Each coordinate difference between `X` and each query point is scaled by dividing by a scale value `S`. The default value of `S` is `NS.DistanceParameter` if `NS.Distance` is `'seuclidean'`, otherwise the default is the standard deviation computed from `X`, `S=nanstd(X)`. To specify another value for `S`, use the `'Scale'` argument.
- `'cityblock'` — City block distance.
- `'chebychev'` — Chebychev distance (maximum coordinate difference).
- `'minkowski'` — Minkowski distance.
- `'mahalanobis'` — Mahalanobis distance, which is computed using a positive definite covariance matrix `C`. The default value of `C` is `nancov(X)`. To change the value of `C`, use the `Cov` parameter.
- `'cosine'` — One minus the cosine of the included angle between observations (treated as vectors).
- `'correlation'` — One minus the sample linear correlation between observations (treated as sequences of values).
- `'spearman'` — One minus the sample Spearman's rank correlation between observations (treated as sequences of values).

- 'hamming' — Hamming distance, which is the percentage of coordinates that differ.
- 'jaccard' — One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ.
- custom distance function — A distance function specified using @ (for example, @distfun). A distance function must be of the form function D2 = distfun(ZI, ZJ), taking as arguments a 1-by- n vector ZI containing a single row of from X or from the query points Y, an $m2$ -by- n matrix ZJ containing multiple rows of X or Y, and returning an $m2$ -by-1 vector of distances D2, whose j th element is the distance between the observations ZI and ZJ(j ,:).

Default is NS.Distance. For more information on these distance metrics, see “Distance Metrics” on page 13-9.

P

A positive scalar, p , indicating the exponent of the Minkowski distance. This parameter is only valid if knnsearch uses the 'minkowski' distance metric. Default is NS.Distance if NS.Distance is 'minkowski' and 2 otherwise.

Cov

A positive definite matrix indicating the covariance matrix when computing the Mahalanobis distance. This parameter is only valid when knnsearch uses the 'mahalanobis' distance metric. Default is NS.Distance if NS.Distance is 'mahalanobis', or nancov(X) otherwise.

Scale

A vector S with the length equal to the number of columns in X. Each coordinate of X and each query point is scaled by the corresponding element of S when computing the standardized Euclidean distance. This parameter is only valid when Distance is 'seuclidean'. Default is nanstd(X).

ExhaustiveSearcher.knnsearch

Examples

Create an ExhaustiveSearcher object specifying 'cosine' as the distance metric. Perform a k -nearest neighbors search on the object using the mahalanobis metric and compare the results:

```
load fisheriris
x = meas(:,3:4);
exhaustiveobj = ExhaustiveSearcher(x,'Distance','cosine')

exhaustiveobj =

    ExhaustiveSearcher

    Properties:
        X: [150x2 double]
        Distance: 'cosine'
        DistParameter: []

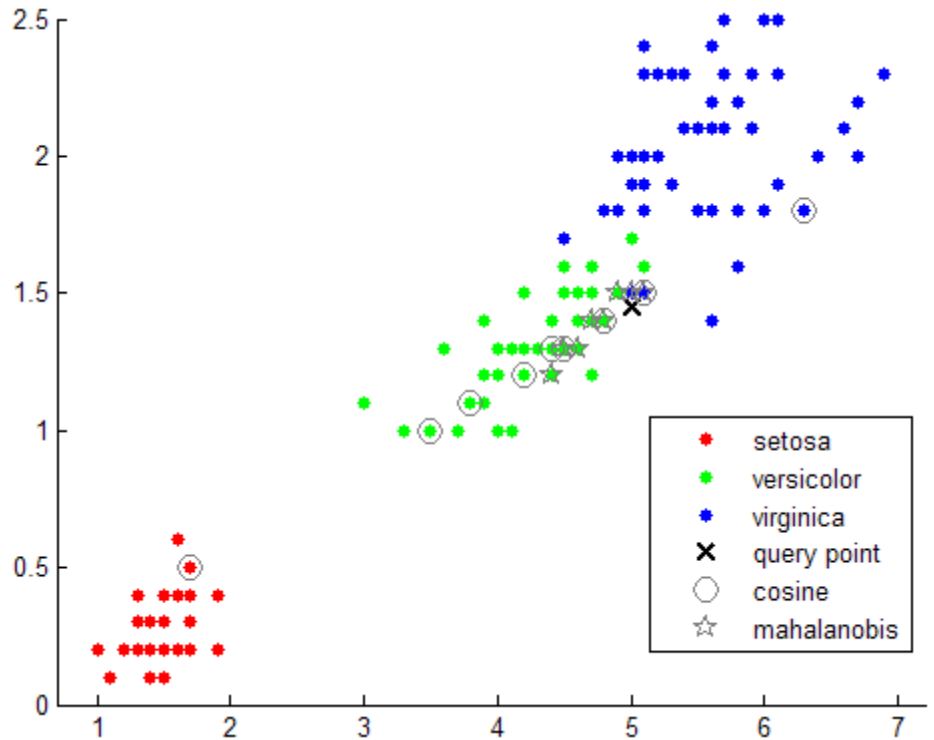
% Perform a knnsearch between x and a query point, using
% first cosine then mahalanobis distance metrics:
newpoint = [5 1.45];
[n,d]=knnsearch(exhaustiveobj,newpoint,'k',10);
[nmah,dmah] = knnsearch(exhaustiveobj,newpoint,'k',10,...
    'distance','mahalanobis');

% Visualize the results of the two different nearest
% neighbors searches:

% First plot the training data:
gscatter(x(:,1),x(:,2),species)
% Plot an X for the query point:
line(newpoint(1),newpoint(2),'marker','x','color','k',...
    'markersize',10,'linewidth',2,'linestyle','none')
% Use circles to denote the cosine nearest neighbors:
line(x(n,1),x(n,2),'color',[.5 .5 .5],'marker','o',...
    'linestyle','none','markersize',10)
% Use pentagrams to denote the mahalanobis nearest neighbors:
line(x(nmah,1),x(nmah,2),'color',[.5 .5 .5],'marker','p',...
```



```
'linestyle','none','markersize',10)  
legend('setosa','versicolor','virginica','query point',...  
       'cosine','mahalanobis')  
set(legend,'location','best')
```



Algorithms

For information on a specific search algorithm, see “Distance Metrics” on page 13-9.

See Also

[createns](#) | [ExhaustiveSearcher](#) | [KDTreeSearcher.knnsearch](#) | [knnsearch](#) | [rangesearch](#)

How To

- “*k*-Nearest Neighbor Search and Radius Search” on page 13-12

ExhaustiveSearcher.knnsearch

- “Distance Metrics” on page 13-9

Purpose

Find k -nearest neighbors using KDTreeSearcher object

Syntax

```
IDX = knnsearch(NS,Y)
[IDX,D] = knnsearch(NS,Y)
[IDX,D] = knnsearch(NS,Y, 'Name', Value)
```

Description

`IDX = knnsearch(NS,Y)` finds the nearest neighbor (closest point) in `NS.X` for each point in `Y`. Rows of `Y` correspond to observations and columns correspond to features. `Y` must have the same number of columns as `NS.X`. `IDX` is a column vector with n_y rows, where n_y is the number of rows in `Y`. Each row in `IDX` contains the index of observation in `NS.X` which has the smallest distance to the corresponding observation in `Y`.

`[IDX,D] = knnsearch(NS,Y)` returns a column vector `D` containing the distances between each observation in `Y` and the corresponding closest observation in `NS.X`. That is, `D(i)` is the distance between `NS.X(IDX(i),:)` and `Y(i,:)`.

`[IDX,D] = knnsearch(NS,Y, 'Name', Value)` accepts one or more comma-separated name/value pairs. Specify *Name* inside single quotes.

Input Arguments

Name-Value Pair Arguments

K

A positive integer, k , specifying the number of nearest neighbors in `NS.X` for each point in `Y`. Default is 1. `IDX` and `D` are n_y -by- k matrices. `D` sorts the distances in each row in ascending order. Each row in `IDX` contains the indices of the k closest neighbors in `NS.X` corresponding to the k smallest distances in `D`.

Distance

Select one of the following distance algorithms.

- 'euclidean' — Euclidean distance (default).
- 'cityblock' — City block distance.

KDTreeSearcher.knnsearch

- 'chebychev' — Chebychev distance (maximum coordinate difference).
- 'minkowski' — Minkowski distance.

Default is `NS.Distance`. For more information on these distance metrics, see “Distance Metrics” on page 13-9.

IncludeTies

A logical value indicating whether `knnsearch` includes all the neighbors whose distance values are equal to the k th smallest distance. If `IncludeTies` is `true`, `knnsearch` includes all these neighbors. In this case, `IDX` and `D` are $n \times k$ cell arrays. Each row in `IDX` and `D` contains a vector with at least k numeric numbers. `D` sorts the distances in each vector in ascending order. Each row in `IDX` contains the indices of the closest neighbors corresponding to these smallest distances in `D`.

Default: `false`

P

A positive scalar, p , indicating the exponent of the Minkowski distance. This parameter is only valid when the `Distance` is 'minkowski'. Default is `NS.DistanceParameter` if `NS.Distance` is 'minkowski' and 2 otherwise.

Examples

Create a `KDTreeSearcher` object specifying 'minkowski' as the distance metric with an exponent of 5. Perform a k -nearest neighbors search on the object using the chebychev metric and compare the results:

```
load fisheriris
x = meas(:,3:4);
kdtreeNS = KDTreeSearcher(x,'Distance','minkowski','P',5)

kdtreeNS =

    KDTreeSearcher
```

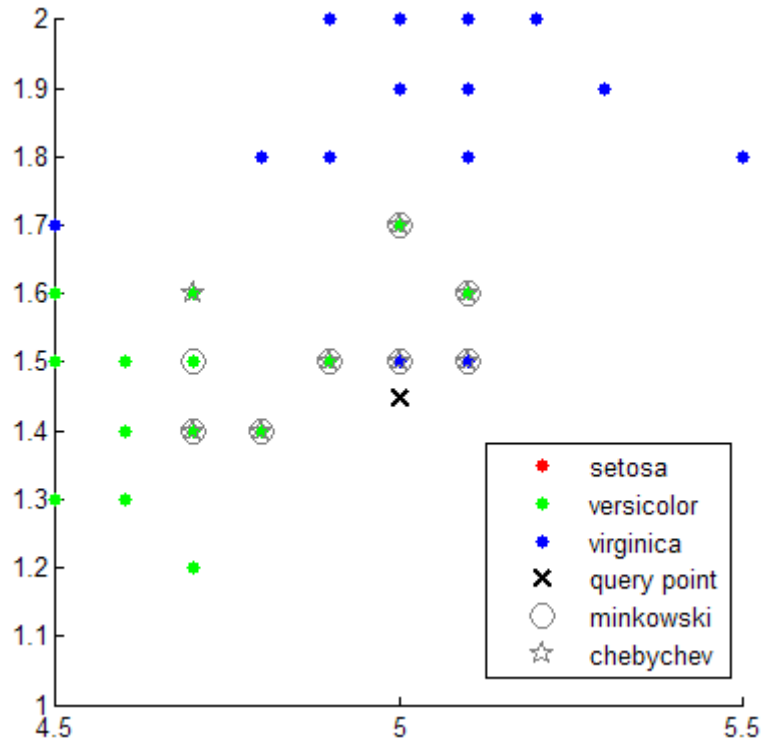
```
Properties:
    BucketSize: 50
           X: [150x2 double]
           Distance: 'minkowski'
    DistParameter: 5

% Perform a knnsearch between X and a query point, using
% first Minkowski then Chebychev distance metrics:
newpoint = [5 1.45];
[n,d]=knnsearch(kdtreeNS,newpoint,'k',10);
[ncb,dcb] = knnsearch(kdtreeNS,newpoint,'k',10,...
    'distance','chebychev');

% Visualize the results of the two different nearest
% neighbors searches:

% First plot the training data:
gscatter(x(:,1),x(:,2),species)
% Zoom in on the points of interest:
set(gca,'xlim',[4.5 5.5],'ylim',[1 2]); axis square
% Plot an X for the query point:
line(newpoint(1),newpoint(2),'marker','x','color','k',...
    'markersize',10,'linewidth',2,'linestyle','none')
% Use circles to denote the Minkowski nearest neighbors:
line(x(n,1),x(n,2),'color',[.5 .5 .5],'marker','o',...
    'linestyle','none','markersize',10)
% Use pentagrams to denote the Chebychev nearest neighbors:
line(x(ncb,1),x(ncb,2),'color',[.5 .5 .5],'marker','p',...
    'linestyle','none','markersize',10)
legend('setosa','versicolor','virginica','query point',...
    'minkowski','chebychev')
set(legend,'location','best')
```

KDTreeSearcher.knnsearch



Algorithms

For information on a specific search algorithm, see “Distance Metrics” on page 13-9.

References

[1] Friedman, J. H., Bentely, J., and Finkel, R. A. (1977). *An Algorithm for Finding Best Matches in Logarithmic Expected Time*, ACM Transactions on Mathematical Software 3, 209.

See Also

[createns](#) | [ExhaustiveSearcher](#) | [ExhaustiveSearcher.knnsearch](#) | [knnsearch](#) | [rangersearch](#)

How To

• “*k*-Nearest Neighbor Search and Radius Search” on page 13-12

- “Distance Metrics” on page 13-9

knnsearch

Purpose Find k -nearest neighbors using data

Syntax

```
IDX = knnsearch(X,Y)
[IDX,D] = knnsearch(X,Y)
[IDX,D] = knnsearch(X,Y, 'Name', Value)
```

Description `IDX = knnsearch(X,Y)` finds the nearest neighbor in X for each point in Y . X is an m_x -by- n matrix and Y is an m_y -by- n matrix. Rows of X and Y correspond to observations and columns correspond to variables. `IDX` is a column vector with m_y rows. Each row in `IDX` contains the index of nearest neighbor in X for the corresponding row in Y .

`[IDX,D] = knnsearch(X,Y)` returns an m_y -by-1 vector `D` containing the distances between each observation in Y and the corresponding closest observation in X . That is, `D(i)` is the distance between $X(\text{IDX}(i), :)$ and $Y(i, :)$.

`[IDX,D] = knnsearch(X,Y, 'Name', Value)` accepts one or more optional comma-separated name/value pairs. Specify *Name* inside single quotes.

`knnsearch` does not save a search object. To create a search object, use `createns`.

Tips

- For a fixed positive integer K , `knnsearch` finds the K points in X that are nearest each point in Y . In contrast, for a fixed positive real value r , `rangesearch` finds all the points in X that are within a distance r of each point in Y .

Input Arguments

Name-Value Pair Arguments

K

Positive integer specifying the number of nearest neighbors in X for each point in Y . Default is 1. `IDX` and `D` are m_y -by- K matrices. `D` sorts the distances in each row in ascending order. Each row in `IDX` contains the indices of the K closest neighbors in X corresponding to the K smallest distances in `D`.

IncludeTies

A logical value indicating whether `knnsearch` includes all the neighbors whose distance values are equal to the *K*th smallest distance. If `IncludeTies` is true, `knnsearch` includes all these neighbors. In this case, `IDX` and `D` are *m_y*-by-1 cell arrays. Each row in `IDX` and `D` contains a vector with at least *K* numeric numbers. `D` sorts the distances in each vector in ascending order. Each row in `IDX` contains the indices of the closest neighbors corresponding to these smallest distances in `D`.

Default: false

NSMethod

Nearest neighbors search method. Value is either:

- 'kdtree' — Creates and uses a Kd-tree to find nearest neighbors. This is the default value when the number of columns of *X* is less than 10, *X* is not sparse, and the distance measure is one of the following measures. 'kdtree' is only valid when the distance measure is one of the following:
 - 'euclidean'
 - 'cityblock'
 - 'minkowski'
 - 'chebychev'
- 'exhaustive' — Uses the exhaustive search algorithm by computing the distance values from all the points in *X* to each point in *Y* to find nearest neighbors.

Distance

A string or a function handle specifying the distance metric. The value can be one of the following:

- 'euclidean' — Euclidean distance (default).

- 'seuclidean' — Standardized Euclidean distance. Each coordinate difference between rows in X and the query matrix is scaled by dividing by the corresponding element of the standard deviation computed from X , $S = \text{nanstd}(X)$. To specify another value for S , use the `Scale` argument.
- 'cityblock' — City block distance.
- 'chebychev' — Chebychev distance (maximum coordinate difference).
- 'minkowski' — Minkowski distance. The default exponent is 2. To specify a different exponent, use the 'P' argument.
- 'mahalanobis' — Mahalanobis distance, computed using a positive definite covariance matrix C . The default value of C is $\text{nancov}(X)$. To change the value of C , use the `Cov` parameter.
- 'cosine' — 1 minus the cosine of the included angle between observations (treated as vectors).
- 'correlation' — One minus the sample linear correlation between observations (treated as sequences of values).
- 'spearman' — One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
- 'hamming' — Hamming distance, which is the percentage of coordinates that differ.
- 'jaccard' — One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ.
- custom distance function — A distance function specified using `@` (for example, `@distfun`). A distance function must be of the form function $D2 = \text{distfun}(ZI, ZJ)$, taking as arguments a 1-by- n vector ZI containing a single row of X or Y , an $m2$ -by- n matrix ZJ containing multiple rows of X or Y , and returning an $m2$ -by-1 vector of distances $D2$, whose j th element is the distance between the observations ZI and $ZJ(j,:)$.

For more information on these distance metrics, see “Distance Metrics” on page 13-9.

P

A positive scalar, p , indicating the exponent of the Minkowski distance. This parameter is only valid if the Distance is 'minkowski'. Default is 2.

Cov

A positive definite matrix indicating the covariance matrix when computing the Mahalanobis distance. This parameter is only valid when Distance is 'mahalanobis'. Default is `nancov(X)`.

Scale

A vector `S` containing nonnegative values, with length equal to the number of columns in `X`. Each coordinate of `X` and each query point is scaled by the corresponding element of `S` when computing the standardized Euclidean distance. This argument is only valid when Distance is 'seuclidean'. Default is `nanstd(X)`.

BucketSize

The maximum number of data points in the leaf node of the *kd*-tree. This argument is only meaningful when using the *kd*-tree search method. Default is 50.

Examples

Find the 10 nearest neighbors in `x` to each point in `y` using first the 'minkowski' distance metric with a p value of 5, and then using the 'chebychev' distance metric. Visually compare the results:

```
load fisheriris
x = meas(:,3:4);
y = [5 1.45;6 2;2.75 .75];

% Perform a knnsearch between x and the query points in y,
% using first Minkowski then Chebychev distance metrics.
[n,d]=knnsearch(x,y,'k',10,'distance','minkowski','p',5);
[ncb,dcb] = knnsearch(x,y,'k',10,...
    'distance','chebychev');
```

knnsearch

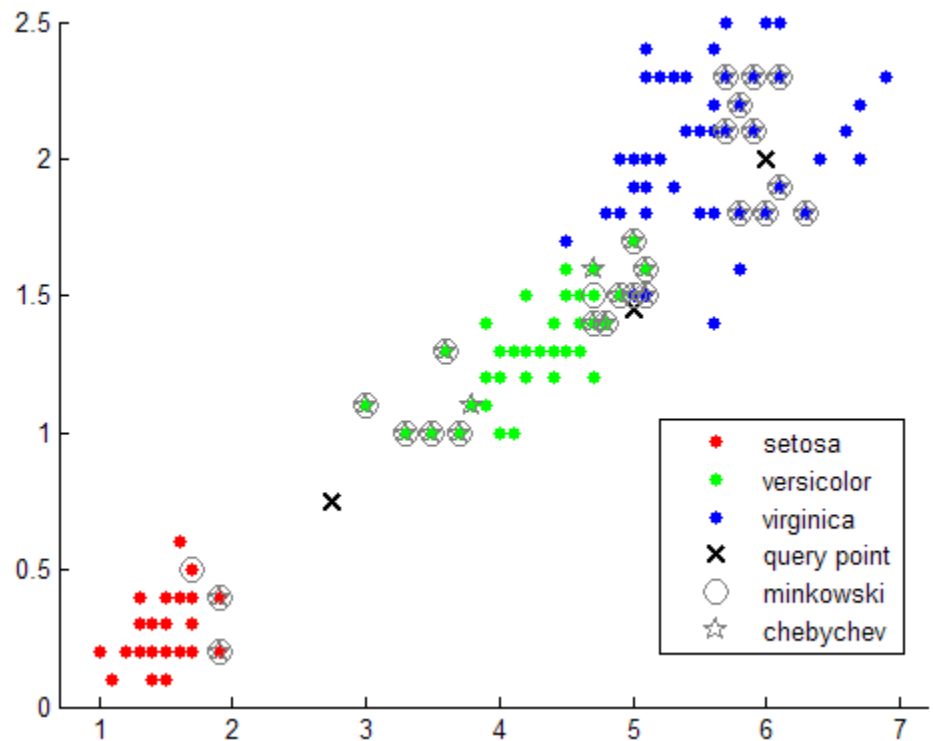
```
% Visualize the results of the two different nearest
% neighbors searches.

% First plot the training data.
gscatter(x(:,1),x(:,2),species)

% Plot an X for the query points.
line(y(:,1),y(:,2),'marker','x','color','k',...
      'markersize',10,'linewidth',2,'linestyle','none')

% Use circles to denote the Minkowski nearest neighbors.
line(x(n,1),x(n,2),'color',[.5 .5 .5],'marker','o',...
      'linestyle','none','markersize',10)

% Use pentagrams to denote the Chebychev nearest neighbors.
line(x(ncb,1),x(ncb,2),'color',[.5 .5 .5],'marker','p',...
      'linestyle','none','markersize',10)
legend('setosa','versicolor','virginica','query point',...
      'minkowski','chebychev')
set(legend,'location','best')
```



Algorithms

For information on a specific search algorithm, see “Distance Metrics” on page 13-9.

References

[1] Friedman, J. H., Bentley, J., and Finkel, R. A. (1977) An Algorithm for Finding Best Matches in Logarithmic Expected Time, ACM Transactions on Mathematical Software 3, 209.

See Also

createns | KDTreeSearcher.knnsearch | ExhaustiveSearcher.knnsearch | rangearch

How To

• “*k*-Nearest Neighbor Search and Radius Search” on page 13-12

kruskalwallis

Purpose Kruskal-Wallis test

Syntax

```
p = kruskalwallis(X)
p = kruskalwallis(X,group)
p = kruskalwallis(X,group,displayopt)
[p,table] = kruskalwallis(...)
[p,table,stats] = kruskalwallis(...)
```

Description `p = kruskalwallis(X)` performs a Kruskal-Wallis test to compare samples from two or more groups. Each column of the m -by- n matrix X represents an independent sample containing m mutually independent observations. The function compares the medians of the samples in X , and returns the p -value for the null hypothesis that all samples are drawn from the same population (or equivalently, from different populations with the same distribution). Note that the Kruskal-Wallis test is a nonparametric version of the classical one-way ANOVA, and an extension of the Wilcoxon rank sum test to more than two groups.

If the p -value is near zero, this casts doubt on the null hypothesis and suggests that at least one sample median is significantly different from the others. The choice of a critical p -value to determine whether the result is judged statistically significant is left to the researcher. It is common to declare a result significant if the p -value is less than 0.05 or 0.01.

The `kruskalwallis` function displays two figures. The first figure is a standard ANOVA table, calculated using the ranks of the data rather than their numeric values. Ranks are found by ordering the data from smallest to largest across all groups, and taking the numeric index of this ordering. The rank for a tied observation is equal to the average rank of all observations tied with it. For example, the following table shows the ranks for a small sample.

X value	1.4	2.7	1.6	1.6	3.3	0.9	1.1
Rank	3	6	4.5	4.5	7	1	2

The entries in the ANOVA table are the usual sums of squares, degrees of freedom, and other quantities calculated on the ranks. The usual F statistic is replaced by a chi-square statistic. The p -value measures the significance of the chi-square statistic.

The second figure displays box plots of each column of X (not the ranks of X).

`p = kruskalwallis(X,group)` uses the values in `group` (a character array or cell array) as labels for the box plot of the samples in X , when X is a matrix. Each row of `group` contains the label for the data in the corresponding column of X , so `group` must have length equal to the number of columns in X .

When X is a vector, `kruskalwallis` performs a Kruskal-Wallis test on the samples contained in X , as indexed by input `group` (a categorical variable, vector, character array, or cell array). Each element in `group` identifies the group (i.e., sample) to which the corresponding element in vector X belongs, so `group` must have the same length as X . The labels contained in `group` are also used to annotate the box plot.

It is not necessary to label samples sequentially (1, 2, 3, ...). For example, if X contains measurements taken at three different temperatures, -27° , 65° , and 110° , you could use these numbers as the sample labels in `group`. If a row of `group` contains an empty cell or empty string, that row and the corresponding observation in X are disregarded. NaNs in either input are similarly ignored.

`p = kruskalwallis(X,group,displayopt)` enables the table and box plot displays when `displayopt` is 'on' (default) and suppresses the displays when `displayopt` is 'off'.

`[p,table] = kruskalwallis(...)` returns the ANOVA table (including column and row labels) in cell array `table`.

`[p,table,stats] = kruskalwallis(...)` returns a `stats` structure that you can use to perform a follow-up multiple comparison test. The `kruskalwallis` test evaluates the hypothesis that all samples come from populations that have the same median, against the alternative that the medians are not all the same. Sometimes it is preferable to

kruskalwallis

perform a test to determine which pairs are significantly different, and which are not. You can use the `multcompare` function to perform such tests by supplying the `stats` structure as input.

Assumptions

The Kruskal-Wallis test makes the following assumptions about the data in `X`:

- All samples come from populations having the same continuous distribution, apart from possibly different locations due to group effects.
- All observations are mutually independent.

The classical one-way ANOVA test replaces the first assumption with the stronger assumption that the populations have normal distributions.

Examples

This example compares the material strength study used with the `anova1` function, to see if the nonparametric Kruskal-Wallis procedure leads to the same conclusion. The example studies the strength of beams made from three alloys:

```
strength = [82 86 79 83 84 85 86 87 74 82 ...  
            78 75 76 77 79 79 77 78 82 79];  
  
alloy = {'st','st','st','st','st','st','st','st',...  
         'al1','al1','al1','al1','al1','al1',...  
         'al2','al2','al2','al2','al2','al2'};
```

This example uses both classical and Kruskal-Wallis ANOVA, omitting displays:

```
anova1(strength,alloy,'off')  
ans =  
    1.5264e-004  
  
kruskalwallis(strength,alloy,'off')  
ans =  
    0.0018
```


Both tests find that the three alloys are significantly different, though the result is less significant according to the Kruskal-Wallis test. It is typical that when a data set has a reasonable fit to the normal distribution, the classical ANOVA test is more sensitive to differences between groups.

To understand when a nonparametric test may be more appropriate, let's see how the tests behave when the distribution is not normal. You can simulate this by replacing one of the values by an extreme value (an outlier).

```
strength(20)=120;
anova1(strength,alloy,'off')
ans =
    0.2501
```

```
kruskalwallis(strength,alloy,'off')
ans =
    0.0060
```

Now the classical ANOVA test does not find a significant difference, but the nonparametric procedure does. This illustrates one of the properties of nonparametric procedures - they are often not severely affected by changes in a small portion of the data.

References

[1] Gibbons, J. D. *Nonparametric Statistical Inference*. New York: Marcel Dekker, 1985.

[2] Hollander, M., and D. A. Wolfe. *Nonparametric Statistical Methods*. Hoboken, NJ: John Wiley & Sons, Inc., 1999.

See Also

[anova1](#) | [boxplot](#) | [friedman](#) | [multcompare](#) | [ranksum](#)

How To

- “Grouping Variables” on page 2-72

ksdensity

Purpose Kernel smoothing density estimate

Syntax

```
[f,xi] = ksdensity(x)
f = ksdensity(x,xi)
ksdensity(...)
ksdensity(ax,...)
[f,xi,u] = ksdensity(...)
[...] = ksdensity(...,'Name',value)
```

Description `[f,xi] = ksdensity(x)` computes a probability density estimate of the sample in the vector `x`. `f` is the vector of density values evaluated at the points in `xi`. The estimate is based on a normal kernel function, using a window parameter (`width`) that is a function of the number of points in `x`. The density is evaluated at 100 equally spaced points that cover the range of the data in `x`. `ksdensity` works best with continuously distributed samples.

`f = ksdensity(x,xi)` specifies the vector `xi` of values, where the density estimate is to be evaluated.

`ksdensity(...)` without output arguments produces a plot of the results.

`ksdensity(ax,...)` plots into axes `ax` instead of `gca`.

`[f,xi,u] = ksdensity(...)` also returns the width of the kernel-smoothing window.

`[...] = ksdensity(...,'Name',value)` specifies one or more optional parameter name/value pairs to control the density estimation. Specify *Name* inside single quotes. Valid parameter strings and their possible values are as follows:

Name	Value
censoring	A logical vector of the same length as <code>x</code> , indicating which entries are censoring times. Default is no censoring.
kernel	<p>The type of kernel smoother to use. Choose the value as</p> <ul style="list-style-type: none"> • 'normal' (default) • 'box' • 'triangle' • 'epanechnikov' <p>Alternatively, you can specify some other function, as a function handle or as a string, e.g., <code>@normpdf</code> or <code>'normpdf'</code>. The function must take a single argument that is an array of distances between data values and places where the density is evaluated. It must return an array of the same size containing corresponding values of the kernel function.</p>
npoints	The number of equally spaced points in <code>xi</code> . Default is 100.
support	<ul style="list-style-type: none"> • 'unbounded' allows the density to extend over the whole real line (default). • 'positive' restricts the density to positive values. • A two-element vector gives finite lower and upper bounds for the support of the density.
weights	Vector of the same length as <code>x</code> , assigning weight to each <code>x</code> value.

ksdensity

Name	Value
width	The bandwidth of the kernel-smoothing window. The default is optimal for estimating normal densities, but you may want to choose a smaller value to reveal features such as multiple modes.
function	The function type to estimate, chosen from among <ul style="list-style-type: none">• 'pdf' — density• 'cdf' — cumulative probability• 'icdf' — inverse cumulative probability• 'survivor' — survivor• 'cumhazard' — cumulative hazard functions For 'icdf', <code>f=ksdensity(x,yi,...,'function','icdf')</code> computes the estimated inverse CDF of the values in <code>x</code> , and evaluates it at the probability values specified in <code>yi</code> .

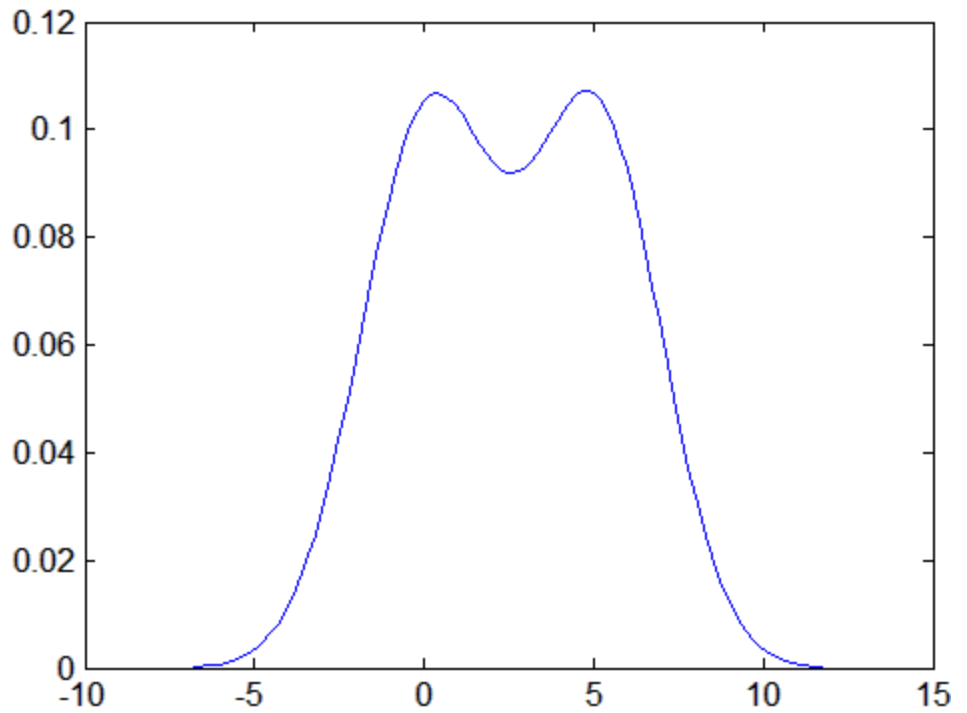
In place of the kernel functions listed above, you can specify another kernel function by using `@` (such as `@normpdf`) or quotes (such as `'normpdf'`). `ksdensity` calls the function with a single argument that is an array containing distances between data values in `x` and locations in `xi` where the density is evaluated. The function must return an array of the same size containing corresponding values of the kernel function. When the `function` parameter value is `'pdf'`, this kernel function returns density values, otherwise it returns cumulative probability values. Specifying a custom kernel when the `function` parameter value is `'icdf'` returns an error.

If the `support` parameter is `'positive'`, `ksdensity` transforms `x` using a log function, estimates the density of the transformed values, and transforms back to the original scale. If `support` is a vector `[L U]`, `ksdensity` uses the transformation $\log((X-L)/(U-X))$. The `width` parameter and `u` outputs are on the scale of the transformed values.

Examples

Generate a mixture of two normal distributions and plots the estimated density:

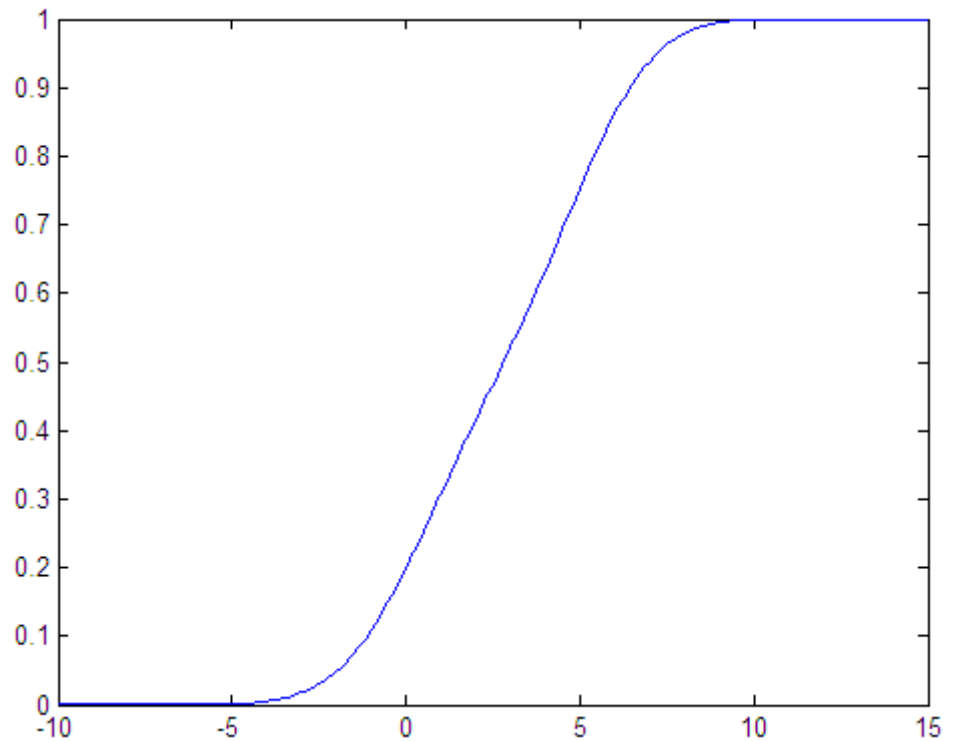
```
x = [randn(30,1); 5+randn(30,1)];  
[f,xi] = ksdensity(x);  
plot(xi,f);
```



Generate a mixture of two normal distributions, and plot the estimated cumulative distribution at a specified set of values:

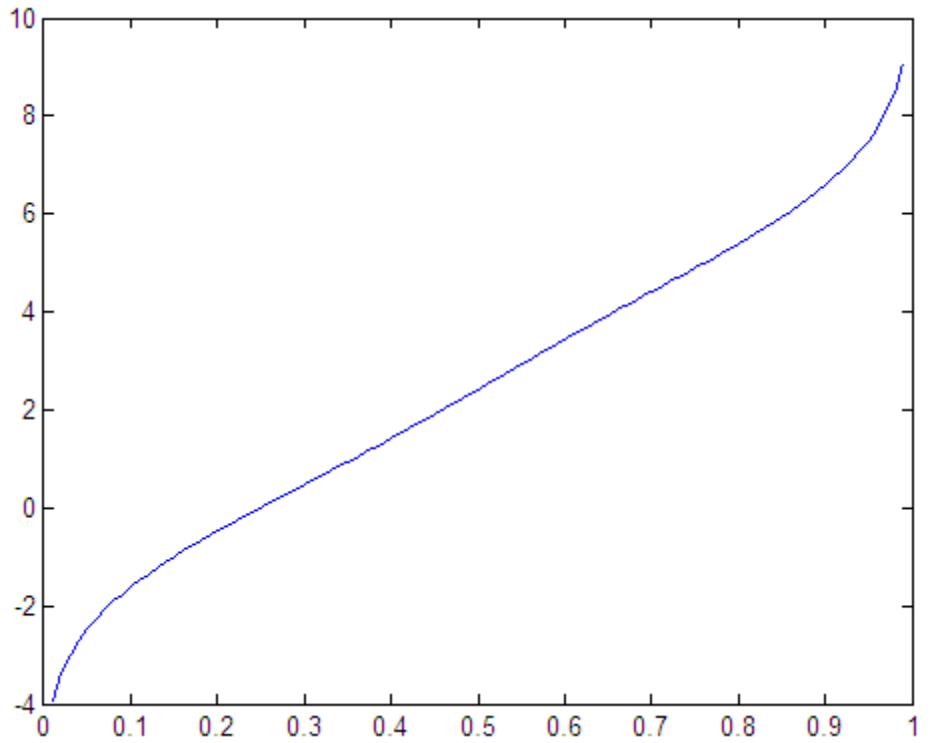
```
x = [randn(30,1); 5+randn(30,1)];  
xi = linspace(-10,15,201);  
f = ksdensity(x,xi,'function','cdf');  
plot(xi,f);
```

ksdensity



Generate a mixture of two normal distributions, and plot the estimated inverse cumulative distribution function at a specified set of values:

```
x = [randn(30,1); 5+randn(30,1)];  
yi = linspace(.01,.99,99);  
g = ksdensity(x,yi,'function','icdf');  
plot(yi,g);
```



References

[1] Bowman, A. W., and A. Azzalini. *Applied Smoothing Techniques for Data Analysis*. New York: Oxford University Press, 1997.

See Also

hist | @

kstest

Purpose One-sample Kolmogorov-Smirnov test

Syntax

```
h = kstest(x)
h = kstest(x,CDF)
h = kstest(x,CDF,alpha)
h = kstest(x,CDF,alpha,type)
[h,p,ksstat,cv] = kstest(...)
```

Description `h = kstest(x)` performs a Kolmogorov-Smirnov test to compare the values in the data vector `x` to a standard normal distribution. The null hypothesis is that `x` has a standard normal distribution. The alternative hypothesis is that `x` does not have that distribution. The result `h` is 1 if the test rejects the null hypothesis at the 5% significance level, 0 otherwise.

The test statistic is:

$$\max(|F(x) - G(x)|)$$

where $F(x)$ is the empirical cdf and $G(x)$ is the standard normal cdf.

`h = kstest(x,CDF)` compares the distribution of `x` to the hypothesized continuous distribution defined by `CDF`, which is either a two-column matrix or a `ProbDist` object of the `ProbDistUnivParam` class or `ProbDistUnivKernel` class. When `CDF` is a matrix, column 1 contains a set of possible x values, and column 2 contains the corresponding hypothesized cumulative distribution function values $G(x)$. If possible, define `CDF` so that column 1 contains the values in `x`. If there are values in `x` not found in column 1 of `CDF`, `kstest` approximates $G(x)$ by interpolation. All values in `x` must lie in the interval between the smallest and largest values in the first column of `CDF`. If the second argument is empty (`[]`), `kstest` uses the standard normal distribution.

The Kolmogorov-Smirnov is only valid for continuous cumulative distribution functions, and the test requires that `CDF` be predetermined. It is not accurate if `CDF` is estimated from the data. To test `x` against normal, lognormal (using the relationship between normal and lognormal), extreme value, Weibull (using the relationship between

extreme value and Weibull), or exponential distribution without specifying the parameters, use `lillietest` instead.

`h = kstest(x,CDF,alpha)` specifies the significance level `alpha` for the test. The default is 0.05.

`h = kstest(x,CDF,alpha,type)` specifies the type of test using one of the following values for the string `type`:

- 'unequal' — Tests the alternative hypothesis that the population cdf is unequal to the specified CDF. This is the default.
- 'larger' — Tests the alternative hypothesis that the population cdf is larger than the specified CDF. The test statistic does not use the absolute value.
- 'smaller' — Tests the alternative hypothesis that the population cdf is smaller than the specified CDF. The test statistic does not use the absolute value.

`[h,p,ksstat,cv] = kstest(...)` also returns the p -value `p`, the test statistic `ksstat`, and the cutoff value `cv` for determining if `ksstat` is significant.

Examples

Generate evenly spaced numbers and perform a Kolmogorov-Smirnov test to see if they come from a standard normal distribution:

```
x = -2:1:4
x =
    -2    -1     0     1     2     3     4

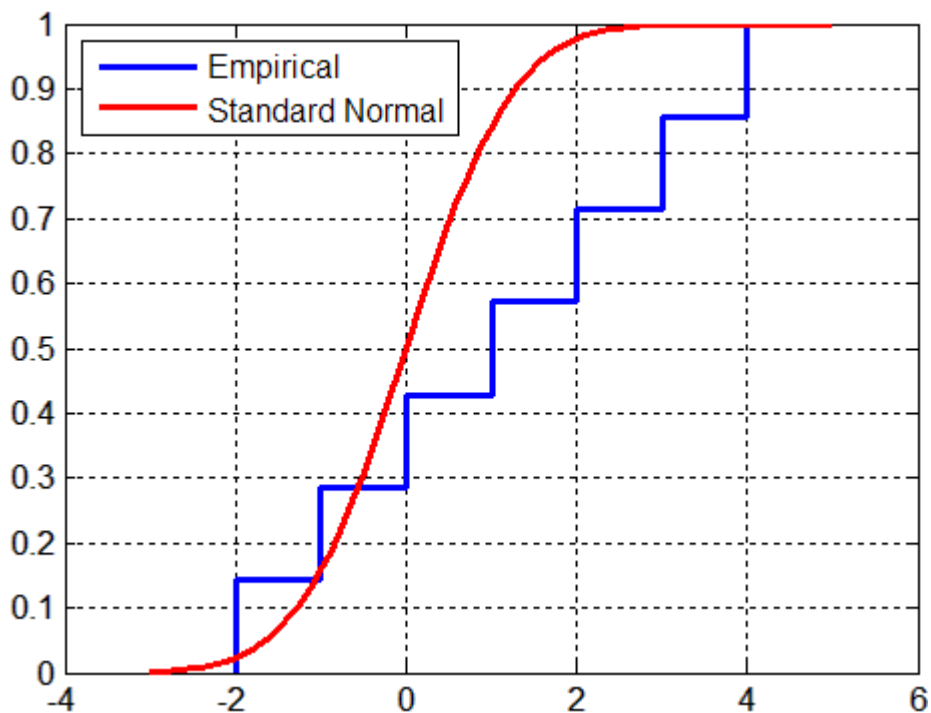
[h,p,k,c] = kstest(x,[],0.05,0)
h =
     0
p =
    0.13632
k =
    0.41277
c =
    0.48342
```

kstest

The test fails to reject the null hypothesis that the values come from a standard normal distribution. This illustrates the difficulty of testing normality in small samples. (The Lilliefors test, implemented by the Statistics Toolbox function `lillietest`, may be more appropriate.)

The following figure illustrates the test statistic:

```
xx = -3:.1:5;
F = cdfplot(x);
hold on
G = plot(xx,normcdf(xx),'r-');
set(F,'LineWidth',2)
set(G,'LineWidth',2)
legend([F G],...
       'Empirical','Standard Normal',...
       'Location','NW')
```



The test statistic k is the maximum difference between the curves.

Setting *type* to 'smaller' tests the alternative that the population cdf is smaller than the normal cdf:

```
[h,p,ksstat] = kstest(x,[],0.05,'smaller')  
h =  
    0  
p =  
    0.068181  
k =  
    0.41277
```

The test statistic is the same as before, but the p value is smaller.

Setting *type* to 'larger' changes the test statistic:

```
[h,p,k] = kstest(x,[],0.05,'larger')
h =
    0
p =
    0.77533
k =
    0.12706
```

References

- [1] Massey, F. J. "The Kolmogorov-Smirnov Test for Goodness of Fit." *Journal of the American Statistical Association*. Vol. 46, No. 253, 1951, pp. 68–78.
- [2] Miller, L. H. "Table of Percentage Points of Kolmogorov Statistics." *Journal of the American Statistical Association*. Vol. 51, No. 273, 1956, pp. 111–121.
- [3] Marsaglia, G., W. Tsang, and J. Wang. "Evaluating Kolmogorov's Distribution." *Journal of Statistical Software*. Vol. 8, Issue 18, 2003.

How To

- `kstest2`
- `lillietest`

Purpose Two-sample Kolmogorov-Smirnov test

Syntax

```
h = kstest2(x1,x2)
h = kstest2(x1,x2,alpha,type)
[h,p] = kstest2(...)
[h,p,ks2stat] = kstest2(...)
```

Description `h = kstest2(x1,x2)` performs a two-sample Kolmogorov-Smirnov test to compare the distributions of the values in the two data vectors `x1` and `x2`. The null hypothesis is that `x1` and `x2` are from the same continuous distribution. The alternative hypothesis is that they are from different continuous distributions. The result `h` is 1 if the test rejects the null hypothesis at the 5% significance level; 0 otherwise.

The test statistic is:

$$\max(|F1(x) - F2(x)|)$$

where $F1(x)$ is the proportion of `x1` values less than or equal to x and $F2(x)$ is the proportion of `x2` values less than or equal to x .

`h = kstest2(x1,x2,alpha)` specifies the significance level `alpha` for the test. The default is 0.05.

`h = kstest2(x1,x2,alpha,type)` specifies the type of test using one of the following values for the string `type`:

- 'unequal' — Tests the alternative hypothesis that the population cdfs are unequal. This is the default.
- 'larger' — Tests the alternative hypothesis that the first population cdf is larger than the second population cdf. The test statistic does not use the absolute value.
- 'smaller' — Tests the alternative hypothesis that the first population cdf is smaller than the second population cdf. The test statistic does not use the absolute value.

`[h,p] = kstest2(...)` also returns the asymptotic p value `p`. The asymptotic p value becomes very accurate for large sample sizes, and

kstest2

is believed to be reasonably accurate for sample sizes n_1 and n_2 such that $(n_1*n_2)/(n_1 + n_2) \geq 4$.

`[h,p,ks2stat] = kstest2(...)` also returns the p value p and the test statistic `ks2stat`.

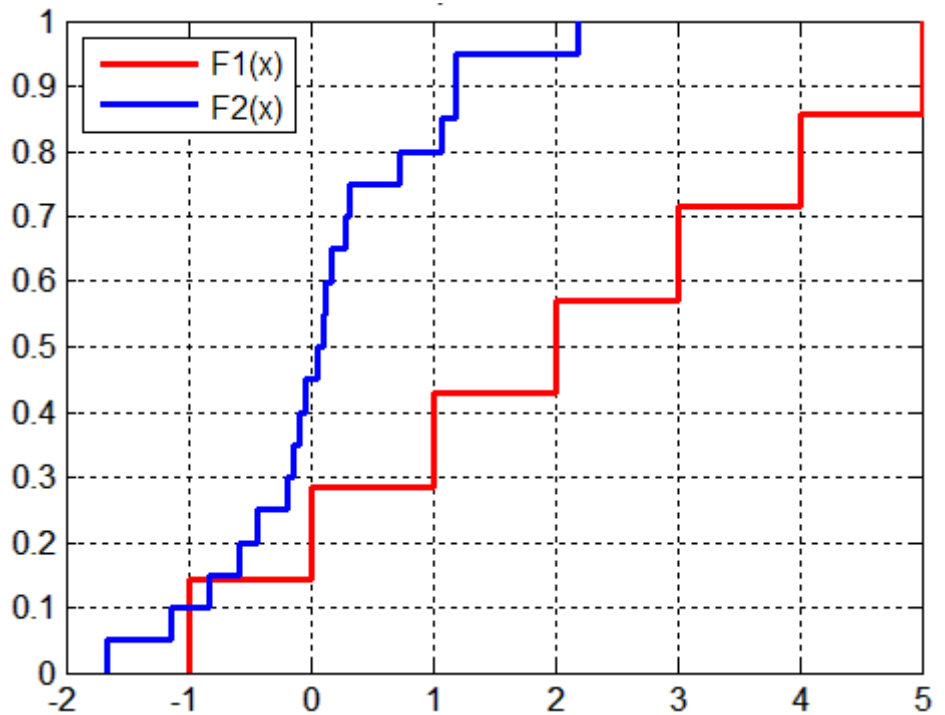
Examples

The following test compares the distributions of a small evenly-spaced sample and a larger normal sample:

```
x = -1:1:5
y = randn(20,1);
[h,p,k] = kstest2(x,y)
h =
    0
p =
    0.0774
k =
    0.5214
```

The following figure illustrates the test statistic:

```
F1 = cdfplot(x);
hold on
F2 = cdfplot(y)
set(F1,'LineWidth',2,'Color','r')
set(F2,'LineWidth',2)
legend([F1 F2],'F1(x)', 'F2(x)', 'Location','NW')
```



The test statistic k is the maximum difference between the curves.

References

- [1] Massey, F. J. "The Kolmogorov-Smirnov Test for Goodness of Fit." *Journal of the American Statistical Association*. Vol. 46, No. 253, 1951, pp. 68–78.
- [2] Miller, L. H. "Table of Percentage Points of Kolmogorov Statistics." *Journal of the American Statistical Association*. Vol. 51, No. 273, 1956, pp. 111–121.
- [3] Marsaglia, G., W. Tsang, and J. Wang. "Evaluating Kolmogorov's Distribution." *Journal of Statistical Software*. Vol. 8, Issue 18, 2003.

[4] Stephens, M. A. “Use of the Kolmogorov-Smirnov, Cramer-Von Mises and Related Statistics Without Extensive Tables.” *Journal of the Royal Statistical Society*. Series B, Vol. 32, No. 1, 1970, pp. 115–122.

How To

- `kstest`
- `lillietest`

Purpose

Kurtosis

Syntax

```
k = kurtosis(X)
k = kurtosis(X,flag)
k = kurtosis(X,flag,dim)
```

Description

`k = kurtosis(X)` returns the sample kurtosis of X . For vectors, `kurtosis(x)` is the kurtosis of the elements in the vector x . For matrices `kurtosis(X)` returns the sample kurtosis for each column of X . For N -dimensional arrays, `kurtosis` operates along the first nonsingleton dimension of X .

`k = kurtosis(X,flag)` specifies whether to correct for bias (`flag` is 0) or not (`flag` is 1, the default). When X represents a sample from a population, the kurtosis of X is biased, that is, it will tend to differ from the population kurtosis by a systematic amount that depends on the size of the sample. You can set `flag` to 0 to correct for this systematic bias.

`k = kurtosis(X,flag,dim)` takes the kurtosis along dimension `dim` of X .

`kurtosis` treats NaNs as missing values and removes them.

Algorithms

Kurtosis is a measure of how outlier-prone a distribution is. The kurtosis of the normal distribution is 3. Distributions that are more outlier-prone than the normal distribution have kurtosis greater than 3; distributions that are less outlier-prone have kurtosis less than 3.

The kurtosis of a distribution is defined as

$$k = \frac{E(x - \mu)^4}{\sigma^4}$$

where μ is the mean of x , σ is the standard deviation of x , and $E(t)$ represents the expected value of the quantity t . `kurtosis` computes a sample version of this population value.

kurtosis

Note Some definitions of kurtosis subtract 3 from the computed value, so that the normal distribution has kurtosis of 0. The `kurtosis` function does not use this convention.

When you set `flag` to 1, the following equation applies:

$$k_1 = \frac{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^4}{\left(\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \right)^2}$$

When you set `flag` to 0, the following equation applies:

$$k_0 = \frac{n-1}{(n-2)(n-3)} ((n+1)k_1 - 3(n-1)) + 3$$

This bias-corrected formula requires that `X` contain at least four elements.

Examples

```
X = randn([5 4])
X =
  1.1650  1.6961  -1.4462  -0.3600
  0.6268  0.0591  -0.7012  -0.1356
  0.0751  1.7971  1.2460  -1.3493
  0.3516  0.2641  -0.6390  -1.2704
 -0.6965  0.8717  0.5774  0.9846

k = kurtosis(X)
k =
  2.1658  1.2967  1.6378  1.9589
```

See Also

`mean` | `moment` | `skewness` | `std` | `var`

Purpose Text labels for levels

Description Text labels for levels. Access labels with `getLabels`.

lasso

Purpose Regularized least-squares regression using lasso or elastic net algorithms

Syntax

```
B = lasso(X,Y)
[B,FitInfo] = lasso(X,Y)
[B,FitInfo] = lasso(X,Y,Name,Value)
```

Description `B = lasso(X,Y)` returns fitted least-squares regression coefficients for a set of regularization coefficients `Lambda`.

`[B,FitInfo] = lasso(X,Y)` returns a structure containing information about the fits.

`[B,FitInfo] = lasso(X,Y,Name,Value)` fits regularized regressions with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

X

Numeric matrix with `n` rows and `p` columns. Each row represents one observation, and each column represents one predictor (variable).

Y

Numeric vector of length `n`, where `n` is the number of rows of `X`. `Y(i)` is the response to row `i` of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Alpha

Scalar value from 0 to 1 (excluding 0) representing the weight of lasso (L^1) versus ridge (L^2) optimization. `Alpha = 1` represents lasso regression, `Alpha` close to 0 approaches ridge regression, and other

values represent elastic net optimization. See “Definitions” on page 20-1118.

Default: 1

CV

Method lasso uses to estimate mean squared error:

- `K`, a positive integer — lasso uses `K`-fold cross validation.
- `cvp`, a `cvpartition` object — lasso uses the cross-validation method expressed in `cvp`. You cannot use a 'leaveout' partition with lasso.
- 'resubstitution' — lasso uses `X` and `Y` to fit the model and to estimate the mean squared error, without cross validation.

Default: 'resubstitution'

DFmax

Maximum number of nonzero coefficients in the model. lasso returns results only for `Lambda` values that satisfy this criterion.

Default: Inf

Lambda

Vector of nonnegative `Lambda` values. See “Definitions” on page 20-1118.

- If you do not supply `Lambda`, lasso calculates the largest value of `Lambda` that gives a nonnull model. In this case, `LambdaRatio` gives the ratio of the smallest to the largest value of the sequence, and `NumLambda` gives the length of the vector.
- If you supply `Lambda`, lasso ignores `LambdaRatio` and `NumLambda`.

Default: Geometric sequence of `NumLambda` values, the largest just sufficient to produce $B = 0$

LambdaRatio

Positive scalar, the ratio of the smallest to the largest `Lambda` value when you do not set `Lambda`.

If you set `LambdaRatio = 0`, `lasso` generates a default sequence of `Lambda` values, and replaces the smallest one with 0.

Default: 1e-4

MCReps

Positive integer, the number of Monte Carlo repetitions for cross validation.

- If CV is 'resubstitution' or a `cvpartition` of type 'resubstitution', `MCReps` must be 1.
- If CV is a `cvpartition` of type 'holdout', `MCReps` must be greater than 1.

Default: 1

NumLambda

Positive integer, the number of `Lambda` values `lasso` uses when you do not set `Lambda`. `lasso` can return fewer than `NumLambda` fits if the residual error of the fits drops below a threshold fraction of the variance of `Y`.

Default: 100

Options

Structure that specifies whether to cross validate in parallel, and specifies the random stream or streams. Create the `Options` structure with `statset`. Option fields:

- `UseParallel` — Set to 'always' to compute in parallel. Default is 'never'.
- `UseSubstreams` — Set to 'always' to compute in parallel in a reproducible fashion. To compute reproducibly, set `Streams` to a

type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'. Default is 'never'.

- **Streams** — A `RandStream` object or cell array consisting of one such object. If you do not specify `Streams`, `lasso` uses the default stream.

PredictorNames

Cell array of strings representing names of the predictor variables, in the order in which they appear in `X`.

Default: {}

RelTol

Convergence threshold for the coordinate descent algorithm (see Friedman, Tibshirani, and Hastie [3]). The algorithm terminates when successive estimates of the coefficient vector differ in the L^2 norm by a relative amount less than `RelTol`.

Default: 1e-4

Standardize

Boolean value specifying whether `lasso` scales `X` and `Y` before fitting the models. `lasso` always centers the data before fitting.

Default: true

Weights

Observation weights, a nonnegative vector of length `n`, where `n` is the number of rows of `X`. `lasso` scales `Weights` to sum to 1.

Default: 1/n * ones(n,1)

Output Arguments

B

Fitted coefficients, a `p`-by-`L` matrix, where `p` is the number of predictors (columns) in `X`, and `L` is the number of `Lambda` values.

FitInfo

Structure containing information about the model fits.

Field in FitInfo	Description
Intercept	Intercept term β_0 for each linear model, a 1-by-L vector
Lambda	Lambda parameters in ascending order, a 1-by-L vector
Alpha	Value of Alpha parameter, a scalar
DF	Number of nonzero coefficients in B for each value of Lambda, a 1-by-L vector
MSE	Mean squared error (MSE), a 1-by-L vector

If you set the CV name-value pair to cross validate, the FitInfo structure contains additional fields.

Field in FitInfo	Description
SE	The standard error of MSE for each Lambda, as calculated during cross validation, a 1-by-L vector
LambdaMinMSE	The Lambda value with minimum MSE, a scalar
Lambda1SE	The largest Lambda such that MSE is within one standard error of the minimum, a scalar
IndexMinMSE	The index of Lambda with value LambdaMinMSE, a scalar
Index1SE	The index of Lambda with value Lambda1SE, a scalar

Definitions

Lasso

For a given value of λ , a nonnegative parameter, lasso solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{2N} \sum_{i=1}^N (y_i - \beta_0 - x_i^T \beta)^2 + \lambda \sum_{j=1}^p |\beta_j| \right),$$

where

- N is the number of observations.
- y_i is the response at observation i .
- x_i is data, a vector of p values at observation i .
- λ is a nonnegative regularization parameter corresponding to one value of Λ .
- The parameters β_0 and β are scalar and p -vector respectively.

As λ increases, the number of nonzero components of β decreases.

The lasso problem involves the L^1 norm of β , as contrasted with the elastic net algorithm.

Elastic Net

For an α strictly between 0 and 1, and a nonnegative λ , elastic net solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{2N} \sum_{i=1}^N (y_i - \beta_0 - x_i^T \beta)^2 + \lambda P_\alpha(\beta) \right),$$

where

$$P_\alpha(\beta) = \frac{(1-\alpha)}{2} \|\beta\|_2^2 + \alpha \|\beta\|_1 = \sum_{j=1}^p \left(\frac{(1-\alpha)}{2} \beta_j^2 + \alpha |\beta_j| \right).$$

Elastic net is the same as lasso when $\alpha = 1$. As α shrinks toward 0, elastic net approaches ridge regression. For other values of α , the penalty term $P_\alpha(\beta)$ interpolates between the L^1 norm of β and the squared L^2 norm of β .

Examples

Remove Redundant Predictors

Construct a data set with redundant predictors, and identify those predictors using cross-validated lasso.

Create a matrix X of 100 five-dimensional normal variables and a response vector Y from just two components of X , with small added noise.

```
X = randn(100,5);  
r = [0;2;0;-3;0]; % only two nonzero coefficients  
Y = X*r + randn(100,1)*.1; % small added noise
```

Construct the default lasso fit.

```
B = lasso(X,Y);
```

Find the coefficient vector for the 25th value in B .

```
B(:,25)
```

```
ans =
```

```
    0  
  1.6093  
    0  
 -2.5865  
    0
```

lasso identifies and removes the redundant predictors.

Plot a Regularized Fit with Cross Validation

Visually examine the cross-validated error of various levels of regularization.

Load the acetylene data and prepare the data with interactions for fitting.

```
load acetylene  
Xs = [x1 x2 x3];
```

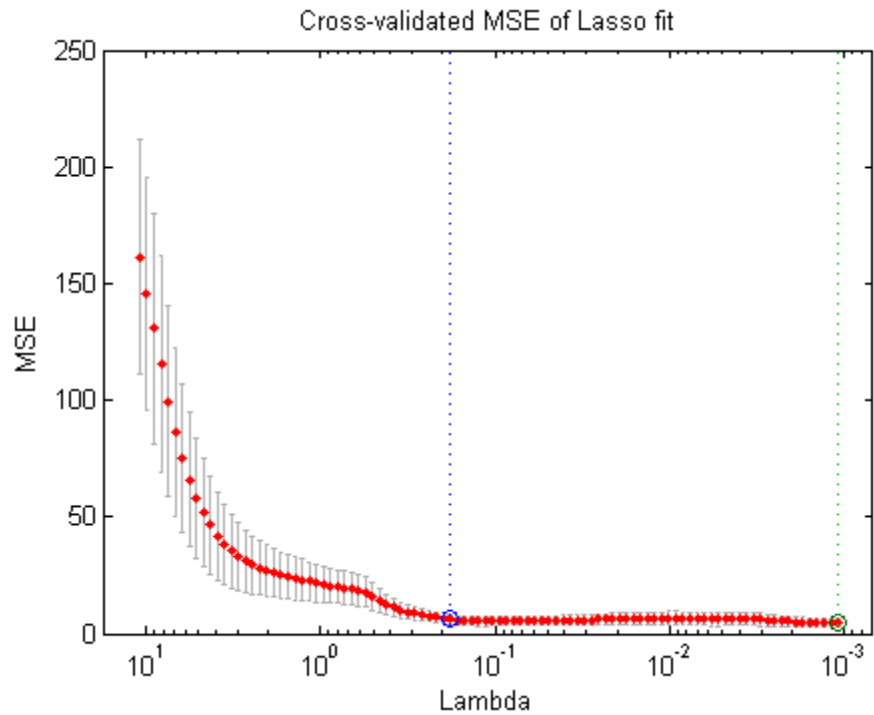
```
X = x2fx(Xs,'interaction');
X(:,1) = []; % No constant term
```

Construct the lasso fit using ten-fold cross validation. Include the FitInfo output so you can plot the result.

```
[B FitInfo] = lasso(X,y,'CV',10);
```

Plot the cross-validated fits.

```
lassoPlot(B,FitInfo,'PlotType','CV');
```



References

- [1] Tibshirani, R. *Regression shrinkage and selection via the lasso*. Journal of the Royal Statistical Society, Series B, Vol 58, No. 1, pp. 267–288, 1996.
- [2] Zou, H. and T. Hastie. *Regularization and variable selection via the elastic net*. Journal of the Royal Statistical Society, Series B, Vol. 67, No. 2, pp. 301–320, 2005.
- [3] Friedman, J., R. Tibshirani, and T. Hastie. *Regularization paths for generalized linear models via coordinate descent*. Journal of Statistical Software, Vol 33, No. 1, 2010. <http://www.jstatsoft.org/v33/i01>
- [4] Hastie, T., R. Tibshirani, and J. Friedman. *The Elements of Statistical Learning*, 2nd edition. Springer, New York, 2008.

See Also

lassoPlot | ridge

How To

- “Lasso and Elastic Net” on page 9-120

Purpose	Lasso or elastic net regularization for generalized linear model regression
Syntax	<pre>B = lassoglm(X,Y) [B,FitInfo] = lassoglm(X,Y) [B,FitInfo] = lassoglm(X,Y,distr) [B,FitInfo] = lassoglm(X,Y,distr,Name,Value)</pre>
Description	<p><code>B = lassoglm(X,Y)</code> returns penalized maximum-likelihood fitted coefficients for a generalized linear model of the response Y to the data matrix X. Y are assumed to have a Gaussian probability distribution.</p> <p><code>[B,FitInfo] = lassoglm(X,Y)</code> returns a structure containing information about the fits.</p> <p><code>[B,FitInfo] = lassoglm(X,Y,distr)</code> fits the model using the probability distribution type for Y as specified in <code>distr</code>.</p> <p><code>[B,FitInfo] = lassoglm(X,Y,distr,Name,Value)</code> fits regularized generalized linear regressions with additional options specified by one or more <code>Name,Value</code> pair arguments.</p>
Input Arguments	<p>X</p> <p>Numeric matrix with n rows and p columns. Each row represents one observation, and each column represents one predictor (variable).</p> <p>Y</p> <p>When <code>distr</code> is not 'binomial', Y is a numeric vector of length n, where n is the number of rows of X. $Y(i)$ is the response to row i of X.</p> <p>When <code>distr</code> is 'binomial', Y is either a:</p> <ul style="list-style-type: none">• Numeric vector of length n, where each entry represents success (1) or failure (0)• Logical vector of length n, where each entry represents success or failure

- Two column numeric matrix, where the first column contains the number of successes for each observation, and the second column contains the total number of trials

distr

Distributional family for the nonsystematic variation in the responses, a string. Choices:

- 'normal'
- 'binomial'
- 'poisson'
- 'gamma'
- 'inverse gaussian'

By default, `lassoglm` uses the canonical link function corresponding to `distr`. Specify another link function using the 'link' name-value pair.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Alpha

Scalar value from 0 to 1 (excluding 0) representing the weight of lasso (L^1) versus ridge (L^2) optimization. `Alpha = 1` represents lasso regression, and other values represent elastic net optimization. `Alpha` close to 0 approaches ridge regression. See “Definitions” on page 20-1118.

Default: 1

CV

Method `lassoglm` uses to estimate deviance:

- `K`, a positive integer — `lassoglm` uses `K`-fold cross validation.
- `cvp`, a `cvpartition` object — `lassoglm` uses the cross-validation method expressed in `cvp`. You cannot use a 'leaveout' partition with `lassoglm`.
- 'resubstitution' — `lassoglm` uses `X` and `Y` to fit the model and to estimate the deviance, without cross validation.

Default: 'resubstitution'

DFmax

Maximum number of nonzero coefficients in the model. `lassoglm` returns results for `Lambda` values that satisfy this criterion.

Default: `Inf`

Lambda

Vector of nonnegative `Lambda` values. See “Lasso” on page 20-1131.

- If you do not supply `Lambda`, `lassoglm` estimates the largest value of `Lambda` that gives a nonnull model. In this case, `LambdaRatio` gives the ratio of the smallest to the largest value of the sequence, and `NumLambda` gives the length of the vector.
- If you supply `Lambda`, `lassoglm` ignores `LambdaRatio` and `NumLambda`.

Default: Geometric sequence of `NumLambda` values, the largest just sufficient to produce $B = 0$

LambdaRatio

Positive scalar, the ratio of the smallest to the largest `Lambda` value when you do not explicitly set `Lambda`.

lassoglm

If you set `LambdaRatio = 0`, `lassoglm` generates a default sequence of `Lambda` values, and replaces the smallest one with 0.

Default: `1e-4`

Link

Specify the mapping between the mean μ of the response and the linear predictor Xb .

Value	Description
'comloglog'	$\log(-\log((1-\mu))) = Xb$
'identity', default for the distribution 'normal'	$\mu = Xb$
'log', default for the distribution 'poisson'	$\log(\mu) = Xb$
'logit', default for the distribution 'binomial'	$\log(\mu/(1-\mu)) = Xb$
'loglog'	$\log(-\log(\mu)) = Xb$
'probit'	$\Phi^{-1}(\mu) = Xb$, where Φ is the normal (Gaussian) CDF function
'reciprocal', default for the distribution 'gamma'	$\mu^{-1} = Xb$

Value	Description
p (a number), default for the distribution 'inverse gaussian' (with $p = -2$)	$\mu^p = Xb$
Cell array of the form {FL FD FI}, containing three function handles, created using @, that define the link (FL), the derivative of the link (FD), and the inverse link (FI). Equivalently, can be a structure of function handles with field Link containing FL, field Derivative containing FD, and field Inverse containing FI.	User-specified link function (see “Custom Link Function” on page 9-145)

MCREps

Positive integer, the number of Monte Carlo repetitions for cross validation.

- If CV is 'resubstitution' or a cvpartition of type 'resubstitution', MCREps must be 1.
- If CV is a cvpartition of type 'holdout', MCREps must be greater than 1.

Default: 1

NumLambda

Positive integer, the number of Lambda values lassoglm uses when you do not set Lambda. lassoglm can return fewer than NumLambda fits if the

deviance of the fits drops below a threshold fraction of the null deviance (deviance of the fit without any predictors X).

Default: 100

Offset

Numeric vector with the same number of rows as X . `lassoglm` uses `Offset` as an additional predictor variable, but keeps its coefficient value fixed at 1.0.

Options

Structure that specifies whether to cross validate in parallel, and specifies the random stream or streams. Create the `Options` structure with `statset`. Option fields:

- `UseParallel` — Set to 'always' to compute in parallel. Default is 'never'.
- `UseSubstreams` — Set to 'always' to compute in parallel in a reproducible fashion. To compute reproducibly, set `Streams` to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'. Default is 'never'.
- `Streams` — `RandStream` object or cell array consisting of one such object. If you do not specify `Streams`, `lassoglm` uses the default stream.

PredictorNames

Cell array of strings representing names of the predictor variables, in the order in which they appear in X .

Default: {}

RelTol

Convergence threshold for the coordinate descent algorithm (see Friedman, Tibshirani, and Hastie [3]). The algorithm terminates when

successive estimates of the coefficient vector differ in the L^2 norm by a relative amount less than `RelTol`.

Default: `1e-4`

Standardize

Boolean value specifying whether `lassoglm` scales `X` and `Y` before fitting the models. `lassoglm` always centers the data before fitting.

Default: `true`

Weights

Observation weights, a nonnegative vector of length `n`, where `n` is the number of rows of `X`. At least two values must be positive.

Default: `1/n * ones(n,1)`

Output Arguments

B

Fitted coefficients, a `p`-by-`L` matrix, where `p` is the number of predictors (columns) in `X`, and `L` is the number of `Lambda` values.

FitInfo

Structure containing information about the model fits.

Field in FitInfo	Description
Alpha	Value of Alpha parameter, a scalar.
Deviance	Deviance of the fitted model for each value of Lambda, a 1-by-L vector. If cross validation was performed, the values for Deviance represent the estimated expected deviance of the model applied to new data, as calculated by cross validation. Otherwise, Deviance is the deviance of the fitted model applied to the data used to perform the fit.

Field in FitInfo	Description
DF	Number of nonzero coefficients in B for each Lambda value, a 1-by-L vector.
Intercept	Intercept term β_0 for each linear model, a 1-by-L vector.
Lambda	Lambda parameters in ascending order, a 1-by-L vector.

If you set the CV name-value pair to cross validate, the `FitInfo` structure contains additional fields.

Field in FitInfo	Description
IndexMinDeviance	Index of Lambda with value <code>LambdaMinDeviance</code> , a scalar.
Index1SE	Index of Lambda with value <code>Lambda1SE</code> , a scalar.
LambdaMinDeviance	Lambda value with minimum expected deviance, as calculated by cross validation, a scalar.
Lambda1SE	Largest Lambda such that Deviance is within one standard error of the minimum, a scalar.
SE	Standard error of Deviance for each Lambda, as calculated during cross validation, a 1-by-L vector.

Definitions

Link Function

A link function $f(\mu)$ maps a distribution with mean μ to a linear model with data X and coefficient vector b using the formula

$$f(\mu) = Xb.$$

Find the formulas for the link functions in the `Link` name-value pair description. Here, “typical” means a link function that is typically used for the listed distribution.

Distributional Family	Link Function (typical, {default})
'normal'	{'identity'}
'binomial'	'comploglog', 'loglog', 'probit', {'logit'}
'poisson'	{'log'}
'gamma'	{'reciprocal'}
'inverse gaussian'	{-2}

Lasso

For a nonnegative value of λ , lasso solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{N} \text{Deviance}(\beta_0, \beta) + \lambda \sum_{j=1}^p |\beta_j| \right),$$

where

- Deviance is the deviance of the model fit to the responses using intercept β_0 and predictor coefficients β . The formula for Deviance depends on the `distr` parameter you supply to `lassoglm`. Minimizing the λ -penalized deviance is equivalent to maximizing the λ -penalized log likelihood.
- N is the number of observations.
- λ is a nonnegative regularization parameter corresponding to one value of `Lambda`.
- Parameters β_0 and β are scalar and p -vector respectively.

As λ increases, the number of nonzero components of β decreases.

The lasso problem involves the L^1 norm of β , as contrasted with the elastic net algorithm.

Elastic Net

For an α strictly between 0 and 1, and a nonnegative λ , elastic net solves the problem

$$\min_{\beta_0, \beta} \left(\frac{1}{N} \text{Deviance}(\beta_0, \beta) + \lambda P_\alpha(\beta) \right),$$

where

$$P_\alpha(\beta) = \frac{(1-\alpha)}{2} \|\beta\|_2^2 + \alpha \|\beta\|_1 = \sum_{j=1}^p \left(\frac{(1-\alpha)}{2} \beta_j^2 + \alpha |\beta_j| \right).$$

Elastic net is the same as lasso when $\alpha = 1$. For other values of α , the penalty term $P_\alpha(\beta)$ interpolates between the L^1 norm of β and the squared L^2 norm of β . As α shrinks toward 0, elastic net approaches ridge regression.

Examples

Lasso Regularization of a Generalized Linear Model

Construct data from a Poisson model, and identify the important predictors using `lassoglm`.

Create data with 20 predictors, and Poisson responses using just three of the predictors, plus a constant.

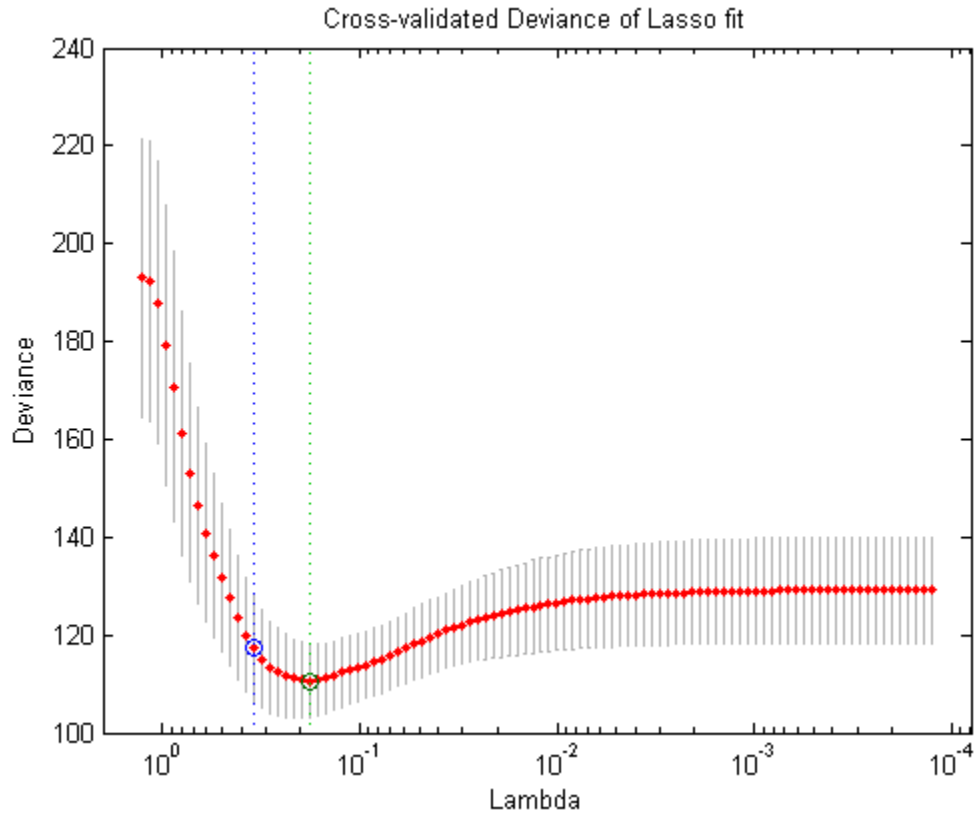
```
rng('default') % for reproducibility
X = randn(100,20);
mu = exp(X(:, [5 10 15]) * [.4;.2;.3] + 1);
y = poissrnd(mu);
```

Construct a cross-validated lasso regularization of a Poisson regression model of the data.

```
[B FitInfo] = lassoglm(X,y,'poisson','CV',10);
```

Examine the cross-validation plot to see the effect of the Lambda regularization parameter.

```
lassoPlot(B,FitInfo,'plottype','CV');
```



The green circle and dashed line locate the Lambda with minimal cross-validation error. The blue circle and dashed line locate the point with minimal cross-validation error plus one standard deviation.

Find the nonzero model coefficients corresponding to the two identified points.

```
minpts = find(B(:,FitInfo.IndexMinDeviance))
```

```
min1pts =  
    3  
    5  
    6  
   10  
   11  
   15  
   16  
  
min1pts = find(B(:,FitInfo.Index1SE))  
  
min1pts =  
    5  
   10  
   15
```

The coefficients from the minimal plus one standard error point are exactly those coefficients used to create the data.

References

- [1] Tibshirani, R. *Regression Shrinkage and Selection via the Lasso*. Journal of the Royal Statistical Society, Series B, Vol. 58, No. 1, pp. 267–288, 1996.
- [2] Zou, H. and T. Hastie. *Regularization and Variable Selection via the Elastic Net*. Journal of the Royal Statistical Society, Series B, Vol. 67, No. 2, pp. 301–320, 2005.
- [3] Friedman, J., R. Tibshirani, and T. Hastie. *Regularization Paths for Generalized Linear Models via Coordinate Descent*. Journal of Statistical Software, Vol. 33, No. 1, 2010. <http://www.jstatsoft.org/v33/i01>
- [4] Hastie, T., R. Tibshirani, and J. Friedman. *The Elements of Statistical Learning*, 2nd edition. Springer, New York, 2008.

[5] Dobson, A. J. *An Introduction to Generalized Linear Models*, 2nd edition. Chapman & Hall/CRC Press, New York, 2002.

[6] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*, 2nd edition. Chapman & Hall/CRC Press, New York, 1989.

[7] Collett, D. *Modelling Binary Data*, 2nd edition. Chapman & Hall/CRC Press, New York, 2003.

See Also

`glmfit` | `lasso` | `lassoPlot` | `ridge`

Related Examples

- “Regularize Poisson Regression” on page 9-176
- “Regularize Logistic Regression” on page 9-180
- “Regularize Wide Data in Parallel” on page 9-187

Concepts

- “Lasso Regularization of Generalized Linear Models” on page 9-176

lassoPlot

Purpose Trace plot of lasso fit

Syntax

```
ax = lassoPlot(B)
ax = lassoPlot(B,FitInfo)
ax = lassoPlot(B,FitInfo,Name,Value)
[ax,figh] = lassoPlot(B,...)
```

Description

`ax = lassoPlot(B)` creates a trace plot of the values in `B` against the L^1 norm of `B`. `ax` is a handle to the plot axis.

`ax = lassoPlot(B,FitInfo)` creates a plot with type depending on the data type of `FitInfo` and the value, if any, of the `plotType` name-value pair.

`ax = lassoPlot(B,FitInfo,Name,Value)` creates a plot with additional options specified by one or more `Name,Value` pair arguments.

`[ax,figh] = lassoPlot(B,...)` returns a handle to the figure window.

Input Arguments

B

Coefficients of a sequence of regression fits, as returned from the `lasso` or `lassoglm` functions. `B` is a `p`-by-`NLambda` matrix, where `p` is the number of predictors, and each column of `B` is a set of coefficients `lasso` calculates using one `Lambda` penalty value.

FitInfo

Information controlling the plot:

- `FitInfo` is a structure, especially as returned from `lasso` or `lassoglm` — `lassoPlot` creates a plot based on the `PlotType` name-value pair.
- `FitInfo` is a vector — `lassoPlot` forms the x -axis of the plot from the values in `FitInfo`. The length of `FitInfo` must equal the number of columns of `B`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Parent

Axis in which to draw the plot.

Default: New plot

PlotType

Choose the plot type when you give a `FitInfo` vector or structure:

FitInfo Type	PlotType	Plot
Vector or Structure	'L1'	<code>plotLasso</code> creates the <i>x</i> -axis from the L^1 norm of the coefficients in <code>B</code> . The <i>x</i> -axis at the top of the plot contains the degrees of freedom (<code>df</code>), meaning the number of nonzero coefficients of <code>B</code> .
Structure	'Lambda'	<code>plotLasso</code> creates the <i>x</i> -axis from the <code>Lambda</code> field of <code>FitInfo</code> . The <i>x</i> -axis at the top of the plot contains the degrees of freedom (<code>df</code>), meaning the number of nonzero coefficients of <code>B</code> .
Cross-Validated Structure	'CV'	<ul style="list-style-type: none"> • For each <code>Lambda</code>, plots an estimate of the mean squared prediction error on new data for the model fitted by lasso with that value of <code>Lambda</code>. • Plots error bars for the estimates. • Plots the value of <code>Lambda</code> with minimum cross-validated MSE.

lassoPlot

FitInfo Type	PlotType	Plot
		<ul style="list-style-type: none">• Plots the greatest Lambda that is within one standard error of minimum MSE (so makes the sparsest model within that region).

Default: 'L1'

PredictorNames

Cell array of strings to label each coefficient of **B**. If the length of **PredictorNames** is less than the number of rows of **B**, the remaining labels are padded with default values.

`lassoPlot` uses the predictor names in **FitInfo** only if:

- You created **FitInfo** with a call to `lasso` that included a **PredictorNames** name-value pair.
- You call `lassoPlot` *without* a **PredictorNames** name-value pair.
- You include **FitInfo** in your `lassoPlot` call.

Default: {'B1', 'B2', ...}

XScale

- 'linear' for linear x-axis
- 'log' for logarithmic scaled x-axis

Default: 'linear', except 'log' for the 'CV' plot type

Output Arguments

ax

Handle to the axis of the plot (see “Setting Axis Parameters”).

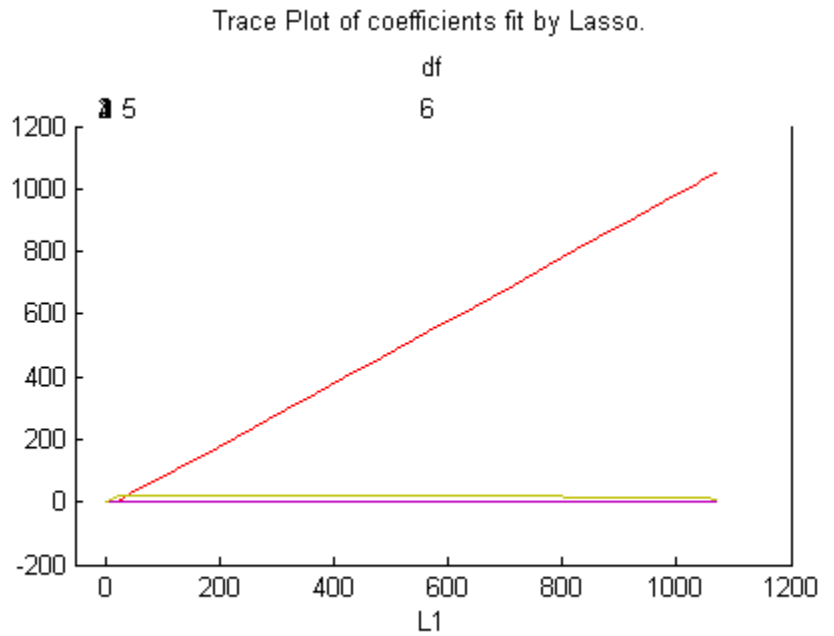
figh

Handle to the figure window (see “Graphics Windows — the Figure”).

Examples

Fit a regularized model of the acetylene data with lasso, and plot the fits with the default plot type:

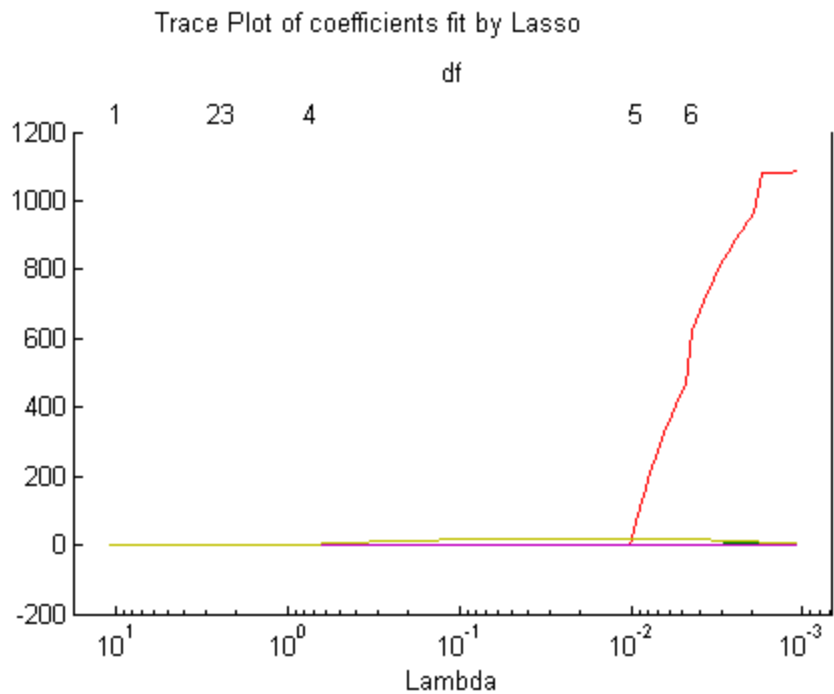
```
load acetylene
X = [x1 x2 x3];
D = x2fx(X,'interaction');
D(:,1) = []; % No constant term
B = lasso(D,y);
lassoPlot(B);
```



Fit a regularized model of the acetylene data with lasso, and plot the fits with the Lambda plot type and logarithmic scaling:

lassoPlot

```
load acetylene
X = [x1 x2 x3];
D = x2fx(X,'interaction');
D(:,1) = []; % No constant term
[B FitInfo] = lasso(D,y);
lassoPlot(B,FitInfo,'PlotType','Lambda','XScale','log');
```



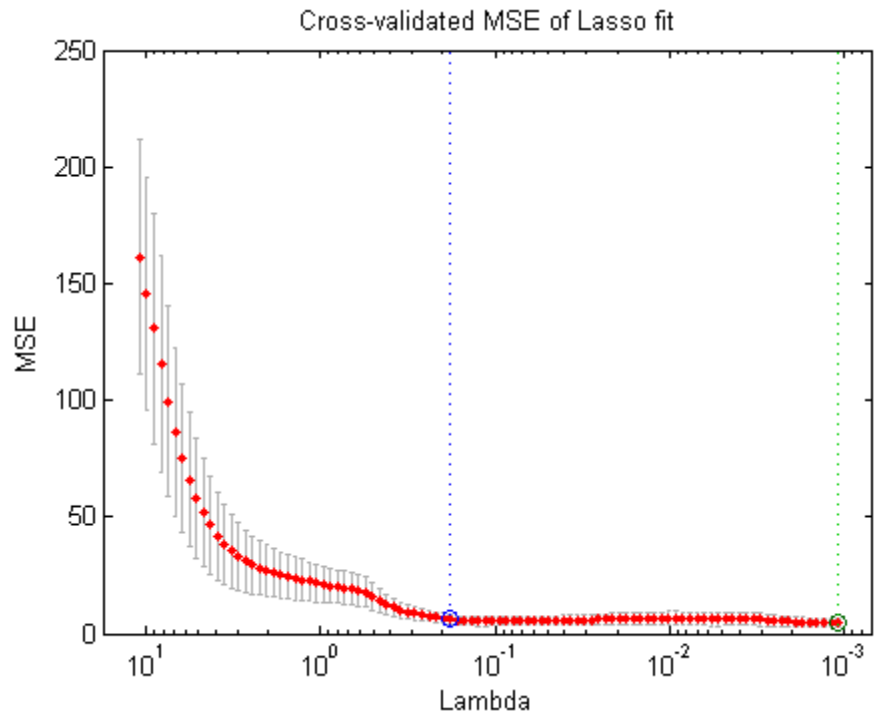
Fit a regularized model of the acetylene data with lasso and cross validation, and plot the cross-validated fits:

```
load acetylene
```

```

X = [x1 x2 x3];
D = x2fx(X,'interaction');
D(:,1) = []; % No constant term
[B FitInfo] = lasso(D,y,'CV',10);
lassoPlot(B,FitInfo,'PlotType','CV');

```



See Also

[lasso](#) | [lassoglm](#)

How To

- “Lasso and Elastic Net” on page 9-120

grandstream.le

Purpose Less than or equal relation for handles

Syntax `h1 <= h2`

Description Handles are equal if they are handles for the same object. All comparisons use a number associated with each handle object. Nothing can be assumed about the result of a handle comparison except that the repeated comparison of two handles in the same MATLAB session will yield the same result. The order of handle values is purely arbitrary and has no connection to the state of the handle objects being compared.

`h1 <= h2` performs element-wise comparisons between handle arrays `h1` and `h2`. `h1` and `h2` must be of the same dimensions unless one is a scalar. The result is a logical array of the same dimensions, where each element is an element-wise `<=` result.

If one of `h1` or `h2` is scalar, scalar expansion is performed and the result will match the dimensions of the array that is not scalar.

`tf = le(h1, h2)` stores the result in a logical array of the same dimensions.

See Also `grandstream` | `eq` | `ge` | `gt` | `lt` | `ne`

Purpose

Interval between points

Description

Number of points to leap over and omit for each point taken from the sequence. The Leap property of a point set contains a positive integer which specifies the number of points in the sequence to leap over and omit for every point taken. The default Leap value is 0, which corresponds to taking every point from the sequence.

Leaping is a technique used to improve the quality of a point set. However, you must choose the Leap values with care; many Leap values create sequences that fail to touch on large sub-hyper-rectangles of the unit hypercube, and so fail to be a uniform quasi-random point set.

Choosing Leap Values for Halton Sets

A known rule for choosing Leap values for Halton sets is to set it to $(P-1)$ where P is a prime number that has not been used to generate one of the dimensions, i.e. for a k -dimensional point set P would be the $(k+1)$ th or greater prime.

Examples

Experiment with different leap values:

```
% No leaping produces the standard Halton sequence.  
P = haltonset(5);  
P(1:5,:)
```

```
% Set a leap of 1. The point set now includes every other  
% point from the sequence.  
P.Lean = 1;  
P(1:5,:)
```

See Also

net | grandset | Skip | subsref | haltonset

dataset.length

Purpose Length of dataset array

Syntax `n = length(A)`

Description `n = length(A)` returns the number of observations in the dataset A.
`length` is equivalent to `size(A,1)`.

See Also `size`

Purpose Length of point set

Syntax length(p)

Description length(p) returns the number of points in the point set p. It is equivalent to size(p, 1).

See Also grandset | size

categorical.length

Purpose Length of categorical array

Syntax `n = length(A)`

Description `n = length(A)` returns the size of the longest dimension of the categorical array `A` when `A` is not empty. If `A` is a vector, this is the same as its length. `length` is equivalent to `max(size(x))` for nonempty arrays, and 0 for empty arrays.

See Also `isempty` | `isscalar` | `size`

Purpose

Element counts by level

Syntax

```
C = levelcounts(A)
C = levelcounts(A,dim)
```

Description

`C = levelcounts(A)` for a categorical vector `A` counts the number of elements in `A` equal to each of the possible levels in `A`. The output is a vector `C` containing those counts, and has as many elements as `A` has levels. For matrix `A`, `C` is a matrix of column counts. For N -dimensional arrays, `levelcounts` operates along the first nonsingleton dimension.

`C = levelcounts(A,dim)` operates along the dimension `dim`.

Examples

Count the number of patients in each age group in the data in `hospital.mat`:

```
load hospital
edges = 0:10:100;
labels = strcat(num2str((0:10:90)', '%d'), {'s'});
disp(labels')
'0s' '10s' '20s' '30s' '40s' '50s' '60s' '70s' '80s' '90s'

AgeGroup = ordinal(hospital.Age, labels, [], edges);
I = islevel(labels, AgeGroup);
disp(I')
0 1 1 1 1 1 1 1 1 1
c = levelcounts(AgeGroup);
disp(c')
0 0 15 41 42 2 0 0 0 0

AgeGroup = droplevels(AgeGroup);
I = islevel(labels, AgeGroup);
disp(I')
0 0 1 1 1 1 0 0 0 0
c = levelcounts(AgeGroup);
disp(c')
15 41 42 2
```

categorical.levelcounts

See Also

`islevel` | `ismember` | `summary`

Purpose	Leverage
Syntax	<pre>h = leverage(data) h = leverage(data,model)</pre>
Description	<p><code>h = leverage(data)</code> finds the leverage of each row (point) in the matrix data for a linear additive regression model.</p> <p><code>h = leverage(data,model)</code> finds the leverage on a regression, using a specified model type, where <i>model</i> can be one of these strings:</p> <ul style="list-style-type: none">• 'linear' - includes constant and linear terms• 'interaction' - includes constant, linear, and cross product terms• 'quadratic' - includes interactions and squared terms• 'purequadratic' - includes constant, linear, and squared terms <p>Leverage is a measure of the influence of a given observation on a regression due to its location in the space of the inputs.</p>
Algorithms	<pre>[Q,R] = qr(x2fx(data,'model')); leverage = (sum(Q' .* Q'))'</pre>
Examples	<p>One rule of thumb is to compare the leverage to $2p/n$ where n is the number of observations and p is the number of parameters in the model. For the Hald data set this value is 0.7692.</p> <pre>load hald h = max(leverage(ingredients,'linear')) h = 0.7004</pre> <p>Since $0.7004 < 0.7692$, there are no high leverage points using this rule.</p>
References	<p>[1] Goodall, C. R. "Computation Using the QR Decomposition." <i>Handbook in Statistics</i>. Vol. 9, Amsterdam: Elsevier/North-Holland, 1993.</p>

leverage

How To

- regstats

Purpose Latin hypercube sample

Syntax

```
X = lhsdesign(n,p)
X = lhsdesign(...,'smooth','off')
X = lhsdesign(...,'criterion',criterion)
X = lhsdesign(...,'iterations',k)
```

Description `X = lhsdesign(n,p)` generates a latin hypercube sample `X` containing `n` values on each of `p` variables. For each column, the `n` values are randomly distributed with one from each interval $(0, 1/n)$, $(1/n, 2/n)$, ..., $(1-1/n, 1)$, and they are randomly permuted.

`X = lhsdesign(...,'smooth','off')` produces points at the midpoints of the above intervals: $0.5/n$, $1.5/n$, ..., $1-0.5/n$. The default is 'on'.

`X = lhsdesign(...,'criterion',criterion)` iteratively generates latin hypercube samples to find the best one according to the criterion *criterion*, which can be one of the following strings.

Criterion	Description
'none'	No iteration.
'maximin'	Maximize minimum distance between points. This is the default.
'correlation'	Reduce correlation.

`X = lhsdesign(...,'iterations',k)` iterates up to `k` times in an attempt to improve the design according to the specified criterion. The default is `k = 5`.

See Also haltonset | sobolset | lhsnorm | unifrnd

lhsnorm

Purpose Latin hypercube sample from normal distribution

Syntax
`X = lhsnorm(mu,sigma,n)`
`X = lhsnorm(mu,sigma,n,flag)`
`[X,Z] = lhsnorm(...)`

Description `X = lhsnorm(mu,sigma,n)` generates a latin hypercube sample X of size n from the multivariate normal distribution with mean vector `mu` and covariance matrix `sigma`. X is similar to a random sample from the multivariate normal distribution, but the marginal distribution of each column is adjusted so that its sample marginal distribution is close to its theoretical normal distribution.

`X = lhsnorm(mu,sigma,n,flag)` controls the amount of smoothing in the sample. If `flag` is 'off', each column has points equally spaced on the probability scale. In other words, each column is a permutation of the values $G(0.5/n)$, $G(1.5/n)$, ..., $G(1-0.5/n)$ where G is the inverse normal cumulative distribution for that column's marginal distribution. If `flag` is 'on' (the default), each column has points uniformly distributed on the probability scale. For example, in place of $0.5/n$ you use a value having a uniform distribution on the interval $(0/n, 1/n)$.

`[X,Z] = lhsnorm(...)` also returns Z , the original multivariate normal sample before the marginals are adjusted to obtain X .

References [1] Stein, M. "Large sample properties of simulations using latin hypercube sampling." *Technometrics*. Vol. 29, No. 2, 1987, pp. 143–151. Correction, Vol. 32, p. 367.

See Also lhsdesign | mvnrnd

Purpose

Lilliefors test

Syntax

```
h = lillietest(x)
h = lillietest(x,alpha)
h = lillietest(x,alpha,distr)
[h,p] = lillietest(...)
[h,p,kstat] = lillietest(...)
[h,p,kstat,critval] = lillietest(...)
[h,p,...] = lillietest(x,alpha,distr,mctol)
```

Description

`h = lillietest(x)` performs a Lilliefors test of the default null hypothesis that the sample in vector `x` comes from a distribution in the normal family, against the alternative that it does not come from a normal distribution. The test returns the logical value `h = 1` if it rejects the null hypothesis at the 5% significance level, and `h = 0` if it cannot. The test treats NaN values in `x` as missing values, and ignores them.

The Lilliefors test is a 2-sided goodness-of-fit test suitable when a fully-specified null distribution is unknown and its parameters must be estimated. This is in contrast to the one-sample Kolmogorov-Smirnov test (see `kstest`), which requires that the null distribution be completely specified. The Lilliefors test statistic is the same as for the Kolmogorov-Smirnov test:

$$KS = \max_x |SCDF(x) - CDF(x)|$$

where *SCDF* is the empirical cdf estimated from the sample and *CDF* is the normal cdf with mean and standard deviation equal to the mean and standard deviation of the sample.

`lillietest` uses a table of critical values computed using Monte Carlo simulation for sample sizes less than 1000 and significance levels between 0.001 and 0.50. The table is larger and more accurate than the table introduced by Lilliefors. Critical values for a test are computed by interpolating into the table, using an analytic approximation when extrapolating for larger sample sizes.

`h = lillietest(x,alpha)` performs the test at significance level `alpha`. `alpha` is a scalar in the range [0.001, 0.50]. To perform the test at a significance level outside of this range, use the `mctol` input argument.

`h = lillietest(x,alpha,distr)` performs the test of the null hypothesis that `x` came from the location-scale family of distributions specified by `distr`. Acceptable values for `distr` are 'norm' (normal, the default), 'exp' (exponential), and 'ev' (extreme value). Using the relationship between normal and lognormal ($\exp(LN) = N$), you can test for lognormal distribution. Similarly using the relationship between extreme value and Weibull ($\log(W) = EV$), you can also test for Weibull distribution using `lillietest`. The Lilliefors test can not be used when the null hypothesis is not a location-scale family of distributions.

`[h,p] = lillietest(...)` returns the p value `p`, computed using inverse interpolation into the table of critical values. Small values of `p` cast doubt on the validity of the null hypothesis. `lillietest` warns when `p` is not found within the tabulated range of [0.001, 0.50], and returns either the smallest or largest tabulated value. In this case, you can use the `mctol` input argument to compute a more accurate p value.

`[h,p,kstat] = lillietest(...)` returns the test statistic `kstat`.

`[h,p,kstat,critval] = lillietest(...)` returns the critical value `critval` for the test. When `kstat > critval`, the null hypothesis is rejected at significance level `alpha`

`[h,p,...] = lillietest(x,alpha,distr,mctol)` computes a Monte Carlo approximation for `p` directly, rather than interpolating into the table of pre-computed values. This is useful when `alpha` or `p` lie outside the range of the table. `lillietest` chooses the number of Monte Carlo replications, `mcreps`, large enough to make the Monte Carlo standard error for `p`, $\sqrt{p*(1-p)/mcreps}$, less than `mctol`.

Examples

Use `lillietest` to determine if car mileage, in miles per gallon (MPG), follows a normal distribution across different makes of cars:

```
load carbig.mat
[h,p] = lillietest(MPG)
```

```
Warning: P is less than the smallest tabulated value, returning 0.001.
```

```
h =  
    1  
p =  
 1.0000e-003
```

This is clear evidence for rejecting the null hypothesis of normality, but the p value returned is just the smallest value in the table of pre-computed values. To find a more accurate p value for the test, run a Monte Carlo approximation using the `mctol` input argument:

```
[h,p] = lillietest(MPG,0.05,'norm',1e-4)  
h =  
    1  
p =  
 8.3333e-006
```

References

- [1] Conover, W. J. *Practical Nonparametric Statistics*. Hoboken, NJ: John Wiley & Sons, Inc., 1980.
- [2] Lilliefors, H. W. “On the Kolmogorov-Smirnov test for the exponential distribution with mean unknown.” *Journal of the American Statistical Association*. Vol. 64, 1969, pp. 387–389.
- [3] Lilliefors, H. W. “On the Kolmogorov-Smirnov test for normality with mean and variance unknown.” *Journal of the American Statistical Association*. Vol. 62, 1967, pp. 399–402.

See Also

`jbtest` | `kstest` | `kstest2` | `cdfplot`

LinearModel

Purpose

Linear regression model class

Description

An object comprising training data, model description, diagnostic information, and fitted coefficients for a linear regression. Predict model responses with the `predict` or `feval` methods.

Construction

`mdl = LinearModel.fit(ds)` or `mdl = LinearModel.fit(X,y)` create a linear model of a dataset array `ds`, or of the responses `y` to a data matrix `X`. For details, see `LinearModel.fit`.

`mdl = LinearModel.stepwise(ds)` or `mdl = LinearModel.stepwise(X,y)` create a linear model of a dataset array `ds`, or of the responses `y` to a data matrix `X`, with unimportant predictors excluded. For details, see `LinearModel.stepwise`.

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors can be numeric, or can be any grouping variable type, such as logical or categorical (see “Grouping Variables” on page 2-72). The response must be numeric or logical.

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

X

Matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as `X`. Each entry in `y` is the response to the data in the corresponding row of `X`.

Properties

CoefficientCovariance

Covariance matrix of coefficient estimates.

CoefficientNames

Cell array of strings containing a label for each coefficient.

Coefficients

Table of coefficient values in a dataset array. `Coefficients` has one row for each coefficient and these columns:

- `Estimate` — Estimated coefficient value
- `SE` — Standard error of the estimate
- `tStat` — t statistic for a test that the coefficient is zero
- `pValue` — p -value for the t statistic

To obtain any of these columns as a vector, index into the property using dot notation. For example, in `mdl` the estimated coefficient vector is

```
beta = mdl.Coefficients.Estimate
```

Use `coefTest` to perform other tests on the coefficients.

DFE

Degrees of freedom for error (residuals), equal to the number of observations minus the number of estimated coefficients.

Diagnostics

Dataset array with the same number of rows as the input data (`ds` or `X`). `Diagnostics` contains diagnostics helpful in finding outliers and influential observations. Many diagnostics describe the effect on the fit of deleting single observations. `Diagnostics` contains the following fields.

LinearModel

Field	Meaning	Utility
Leverage	Diagonal elements of HatMatrix	Leverage indicates to what extent the predicted value for an observation is determined by the observed value for that observation. A value close to 1 indicates that the prediction is largely determined by that observation, with little contribution from the other observations. A value close to 0 indicates the fit is largely determined by the other observations. For a model with P coefficients and N observations, the average value of Leverage is P/N . An observation with Leverage larger than $2 * P/N$ can be regarded as having high leverage.
CooksDistance	Cook's measure of scaled change in fitted values	CooksDistance is a measure of scaled change in fitted values. An observation with CooksDistance larger than three times the mean Cook's distance can be an outlier.
Dffits	Delete-1 scaled differences in fitted values vs. observation number	Dffits is the scaled change in the fitted values for each observation that would result from excluding that observation from the fit. Values with an absolute value larger than $2 * \sqrt{P/N}$ may be considered influential.
S2_i	Delete-1 variance vs. observation number	S2_i is a set of residual variance estimates obtained by deleting each observation in turn. These can be compared with the value of the MSE property.
CovRatio	Delete-1 ratio of determinant of covariance vs. observation number	CovRatio is the ratio of the determinant of the coefficient covariance matrix with each observation deleted in turn to the determinant of the covariance matrix for the full model. Values larger than $1 + 3 * P/N$ or smaller than $1 - 3 * P/N$ indicate influential points.

Field	Meaning	Utility
Dfbetas	Delete-1 scaled differences in covariance estimates vs. observation number	Dfbetas is an N-by-P matrix of the scaled change in the coefficient estimates that would result from excluding each observation in turn. Values larger than $3/\sqrt{N}$ in absolute value indicate that the observation has a large influence on the corresponding coefficient.
HatMatrix	Projection matrix to compute fitted from observed responses	HatMatrix is an N-by-N matrix such that $\text{Fitted} = \text{HatMatrix} * Y$, where Y is the response vector and Fitted is the vector of fitted response values.

Rows not used in the fit because of missing values (in `ObservationInfo.Missing`) contain NaN values.

Rows not used in the fit because of excluded values (in `ObservationInfo.Excluded`) contain NaN values, with the following exception: Delete-1 diagnostics refer to the statistic with and without that observation (row) included in the fit. These diagnostics help identify important observations.

Fitted

Predicted response to the input data by using the model. Use `predict` to compute predictions for other predictor values, or to compute confidence bounds on `Fitted`.

Formula

Object containing information about the model.

LogLikelihood

Log likelihood of the model distribution at the response values, with mean fitted from the model, and other parameters estimated as part of the model fit.

ModelCriterion

AIC and other information criteria for comparing models. A structure with fields:

- AIC — Akaike information criterion
- AICc — Akaike information criterion corrected for sample size
- BIC — Bayesian information criterion
- CAIC — Consistent Akaike information criterion

To obtain any of these values as a scalar, index into the property using dot notation. For example, in a model `mdl`, the AIC value `aic` is:

```
aic = mdl.ModelCriterion.AIC
```

MSE

Mean squared error (residuals), SSE/DFE .

NumCoefficients

Number of coefficients in the model, a positive integer. `NumCoefficients` includes coefficients that are set to zero when the model terms are rank deficient.

NumEstimatedCoefficients

Number of estimated coefficients in the model, a positive integer. `NumEstimatedCoefficients` does not include coefficients that are set to zero when the model terms are rank deficient. `NumEstimatedCoefficients` is the degrees of freedom for regression.

NumObservations

Number of observations the fitting function used in fitting. This is the number of observations supplied in the original dataset or matrix, minus any excluded rows (set with the `Excluded` name-value pair) or rows with missing values.

NumPredictors

Number of variables `LinearModel.fit` used as predictors for fitting.

NumVariables

Number of variables in the data. `NumVariables` is the number of variables in the original dataset when the fit is based on a dataset, or the total number of columns in the predictor matrix and response vector when the fit is based on those arrays. It includes variables, if any, that are not used as predictors or as the response.

ObservationInfo

Dataset with the same number of rows as the input data (ds or X).

Field	Description
Weights	Observation weights. Default is all 1.
Excluded	Logical value, 1 indicates an observation that you excluded from the fit with the <code>Exclude</code> name-value pair.
Missing	Logical value, 1 indicates a missing value in the input. Missing values are not used in the fit.
Subset	Logical value, 1 indicates the observation is not excluded or missing, so is used in the fit.

ObservationNames

Cell array of strings containing the names of the observations used in the fit.

- If the fit is based on a dataset containing observation names, `ObservationNames` uses those names.
- Otherwise, `ObservationNames` is an empty cell array

PredictorNames

LinearModel

Cell array of strings, the names of the predictors used in fitting the model.

Residuals

Dataset array containing a table of residuals, with one row for each observation and these variables.

Field	Description
Raw	Observed minus fitted values.
Pearson	Raw residuals divided by RMSE.
Standardized	Raw residuals divided by their estimated standard deviation.
Studentized	Residual divided by an independent estimate of the residual standard deviation. The residual for observation i is divided by an estimate of the error standard deviation based on all observations except for observation i .

To obtain any of these columns as a vector, index into the property using dot notation. For example, in a model `mdl`, the ordinary raw residual vector `r` is:

```
r = mdl.Residuals.Raw
```

Rows not used in the fit because of missing values (in `ObservationInfo.Missing`) contain NaN values.

Rows not used in the fit because of excluded values (in `ObservationInfo.Excluded`) contain NaN values, with the following exceptions:

- `raw` contains the difference between the observed and predicted values.
- `standardized` is the residual, standardized in the usual way.

- `studentized` matches the standardized values because this residual is not used in the estimate of the residual standard deviation.

ResponseName

String giving naming the response variable.

RMSE

Root mean squared error (residuals), $\sqrt{\text{MSE}}$.

Robust

Structure that is empty unless `LinearModel.fit` constructed the model using robust regression.

Field	Description
<code>WgtFun</code>	Robust weighting function, such as 'bisquare' (see <code>robustfit</code>)
<code>Tune</code>	Value specified for tuning parameter (can be <code>[]</code>)
<code>Weights</code>	Vector of weights used in final iteration of robust fit

Rsquared

Proportion of total sum of squares explained by the model. The ordinary R-squared value relates to the `SSR` and `SST` properties:

$$\text{Rsquared} = \text{SSR}/\text{SST} = 1 - \text{SSE}/\text{SST}.$$

`Rsquared` is a structure with two fields:

- `Ordinary` — Ordinary (unadjusted) R-squared
- `Adjusted` — R-squared adjusted for the number of coefficients

LinearModel

To obtain any of these values as a scalar, index into the property using dot notation. For example, the adjusted R-squared value in `mdl` is

```
r2 = mdl.Rsquared.Adjusted
```

SSE

Sum of squared errors (residuals).

The Pythagorean theorem implies

$$SST = SSE + SSR.$$

SSR

Regression sum of squares, the sum of squared deviations of the fitted values from their mean.

The Pythagorean theorem implies

$$SST = SSE + SSR.$$

SST

Total sum of squares, the sum of squared deviations of `y` from `mean(y)`.

The Pythagorean theorem implies

$$SST = SSE + SSR.$$

Steps

Structure that is empty unless `LinearModel.stepwise` constructed the model.

Field	Description
Start	Formula representing the starting model
Lower	Formula representing the lower bound model, these terms that must remain in the model
Upper	Formula representing the upper bound model, model cannot contain more terms than Upper
Criterion	Criterion used for the stepwise algorithm, such as 'sse'
PEnter	Value of the parameter, such as 0.05
PRemove	Value of the parameter, such as 0.10
History	Dataset representing the steps taken in the fit

The History dataset has one row for each step including the initial fit, and the following variables (columns).

Field	Description
Action	Action taken during this step, one of: <ul style="list-style-type: none"> 'Start' — First step 'Add' — A term is added 'Remove' — A term is removed
TermName	<ul style="list-style-type: none"> 'Start' step: The starting model specification 'Add' or 'Remove' steps: The term moved in that step
Terms	Terms matrix (see <code>modelspec</code> in “Input Arguments” on page 20-709 of <code>LinearModel.fit</code>)
DF	Regression degrees of freedom after this step

LinearModel

Field	Description
delDF	Change in regression degrees of freedom from previous step (negative for steps that remove a term)
Deviance	Deviance (residual sum of squares) at that step
FStat	F statistic that led to this step
PValue	p -value of the F statistic

VariableInfo

Dataset array containing metadata about `Variables`. There is one row for each term in the model, and the following columns.

Field	Description
Class	String giving variable class, such as 'double'
Range	Cell array giving variable range: <ul style="list-style-type: none">• Continuous variable — Two-element vector $[min, max]$, the minimum and maximum values• Categorical variable — Cell array of distinct variable values
InModel	Logical vector, where true indicates the variable is in the model
IsCategorical	Logical vector, where true indicates a categorical variable

VariableNames

Cell array of strings containing names of the variables in the fit.

- If the fit is based on a dataset, this property provides the names of the variables in that dataset.

- If the fit is based on a predictor matrix and response vector, `VariableNames` is the values in the `VarNames` name-value pair of the fitting method.
- Otherwise the variables have the default fitting names.

Variables

Dataset array containing the data, both observations and responses, that the fitting function used to construct the fit. If the fit is based on a dataset array, `Variables` is a copy of that dataset. Otherwise, `Variables` is a dataset created from the input data matrix `X` and response vector `y`.

Methods

<code>addTerms</code>	Add terms to linear regression model
<code>anova</code>	Analysis of variance for linear model
<code>coefCI</code>	Confidence intervals of coefficient estimates of linear model
<code>coefTest</code>	Linear hypothesis test on linear regression model coefficients
<code>disp</code>	Display linear regression model
<code>dwtest</code>	Durbin-Watson test of linear model
<code>feval</code>	Evaluate linear regression model prediction
<code>fit</code>	Create linear regression model
<code>plot</code>	Scatter plot or added variable plot of linear model
<code>plotAdded</code>	Added variable plot or leverage plot for linear model

LinearModel

<code>plotAdjustedResponse</code>	Adjusted response plot for linear regression model
<code>plotDiagnostics</code>	Plot diagnostics of linear regression model
<code>plotEffects</code>	Plot main effects of each predictor in linear regression model
<code>plotInteraction</code>	Plot interaction effects of two predictors in linear regression model
<code>plotResiduals</code>	Plot residuals of linear regression model
<code>plotSlice</code>	Plot of slices through fitted linear regression surface
<code>predict</code>	Predict response of linear regression model
<code>random</code>	Simulate responses for linear regression model
<code>removeTerms</code>	Remove terms from linear model
<code>step</code>	Improve linear regression model by adding or removing terms
<code>stepwise</code>	Create linear regression model by stepwise regression

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Definitions

Hat Matrix

The *hat matrix* H is defined in terms of the data matrix X :

$$H = X(X^T X)^{-1} X^T.$$

The diagonal elements H_{ii} satisfy

$$0 \leq h_{ii} \leq 1$$

$$\sum_{i=1}^n h_{ii} = p,$$

where n is the number of observations (rows of X), and p is the number of coefficients in the regression model.

Leverage

The *leverage* of observation i is the value of the i th diagonal term of the hat matrix H_{ii} . Because the sum of the leverage values is p (the number of coefficients in the regression model), an observation i can be considered to be an outlier if its leverage substantially exceeds p/n , where n is the number of observations.

Cook's Distance

Cook's distance is the scaled change in fitted values. Each element in `CooksDistance` is the normalized change in the vector of coefficients due to the deletion of an observation. The Cook's distance, D_i , of observation i is

$$D_i = \frac{\sum_{j=1}^n (\hat{y}_j - \hat{y}_{j(i)})^2}{p MSE},$$

where

- \hat{y}_j is the j th fitted response value.
- $\hat{y}_{j(i)}$ is the j th fitted response value, where the fit does not include observation i .
- MSE is the mean squared error.
- p is the number of coefficients in the regression model.

LinearModel

Cook's distance is algebraically equivalent to the following expression:

$$D_i = \frac{r_i^2}{pMSE} \left(\frac{h_{ii}}{(1-h_{ii})^2} \right),$$

where r_i is the i th residual, and h_{ii} is the i th leverage value.

CooksDistance is an n -by-1 column vector in the Diagnostics dataset array of the LinearModel object.

Examples

Linear Regression Model of Matrix Data

Fit a linear model of the Hald data.

Load the data.

```
load hald
X = ingredients; % predictor variables
y = heat; % response
```

Fit a default linear model to the data.

```
mdl = LinearModel.fit(X,y)
```

```
mdl =
```

```
Linear regression model:
y ~ 1 + x1 + x2 + x3 + x4
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	62.405	70.071	0.8906	0.39913
x1	1.5511	0.74477	2.0827	0.070822
x2	0.51017	0.72379	0.70486	0.5009
x3	0.10191	0.75471	0.13503	0.89592
x4	-0.14406	0.70905	-0.20317	0.84407

Number of observations: 13, Error degrees of freedom: 8

Root Mean Squared Error: 2.45
R-squared: 0.982, Adjusted R-Squared 0.974
F-statistic vs. constant model: 111, p-value = 4.76e-07

Linear Regression with Categorical Predictor and Nonlinear Model

Fit a model of a dataset array that contains a categorical predictor.
Use a nonlinear response formula.

Load the carsmall data.

```
load carsmall
```

Construct a dataset containing continuous predictor variable `Weight`,
nominal predictor variable `Year`, and response variable `MPG`.

```
ds = dataset(MPG,Weight);  
ds.Year = ordinal(Model_Year);
```

Create a fitted model of `MPG` as a function of `Year`, `Weight`, and `Weight2`.
(You don't have to include `Weight` explicitly in your formula because it
is a lower-order term of `Weight2`. For details, see "Definitions" on page
20-715.)

```
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2')
```

```
mdl =
```

Linear regression model:

```
MPG ~ 1 + Weight + Year + Weight^2
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	54.206	4.7117	11.505	2.6648e-19
Weight	-0.016404	0.0031249	-5.2493	1.0283e-06
Year_76	2.0887	0.71491	2.9215	0.0044137
Year_82	8.1864	0.81531	10.041	2.6364e-16
Weight^2	1.5573e-06	4.9454e-07	3.149	0.0022303

LinearModel

```
Number of observations: 94, Error degrees of freedom: 89
Root Mean Squared Error: 2.78
R-squared: 0.885, Adjusted R-Squared 0.88
F-statistic vs. constant model: 172, p-value = 5.52e-41
```

Robust Linear Regression Model

Fit a linear regression model of the Hald data using robust fitting.

Load the data.

```
load hald
X = ingredients; % predictor variables
y = heat; % response
```

Fit a robust linear model to the data.

```
mdl = LinearModel.fit(X,y,'linear','RobustOpts','on')
```

```
mdl =
```

```
Linear regression model (robust fit):
y ~ 1 + x1 + x2 + x3 + x4
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	60.09	75.818	0.79256	0.4509
x1	1.5753	0.80585	1.9548	0.086346
x2	0.5322	0.78315	0.67957	0.51596
x3	0.13346	0.8166	0.16343	0.87424
x4	-0.12052	0.7672	-0.15709	0.87906

```
Number of observations: 13, Error degrees of freedom: 8
Root Mean Squared Error: 2.65
R-squared: 0.979, Adjusted R-Squared 0.969
F-statistic vs. constant model: 94.6, p-value = 9.03e-07
```

Algorithms

The main fitting algorithm is QR decomposition. For robust fitting, the algorithm is `robustfit`.

Alternatives

To remove redundant predictors in linear regression using lasso or elastic net, use the `lasso` function.

To regularize a regression with correlated terms using ridge regression, use the `ridge` or `lasso` functions.

To regularize a regression with correlated terms using partial least squares, use the `plsregress` function.

See Also

`LinearModel.fit` | `LinearModel.stepwise`

Tutorials

- “Linear Regression Workflow” on page 9-40
- “Robust Regression versus Standard Least-Squares Fit” on page 9-113

How To

- “Linear Regression” on page 9-7

linhpytest

Purpose Linear hypothesis test

Syntax `p = linhpytest(beta,COVB,c,H,dfe)`
`[p,t,r] = linhpytest(...)`

Description `p = linhpytest(beta,COVB,c,H,dfe)` returns the p value p of a hypothesis test on a vector of parameters. `beta` is a vector of k parameter estimates. `COVB` is the k -by- k estimated covariance matrix of the parameter estimates. `c` and `H` specify the null hypothesis in the form $H*b = c$, where `b` is the vector of unknown parameters estimated by `beta`. `dfe` is the degrees of freedom for the `COVB` estimate, or `Inf` if `COVB` is known rather than estimated.

`beta` is required. The remaining arguments have default values:

- `COVB = eye(k)`
- `c = zeros(k,1)`
- `H = eye(K)`
- `dfe = Inf`

If `H` is omitted, `c` must have k elements and it specifies the null hypothesis values for the entire parameter vector.

Note The following functions return outputs suitable for use as the `COVB` input argument to `linhpytest`: `nlinfit`, `coxphfit`, `glmfit`, `mnrfit`, `regstats`, `robustfit`. `nlinfit` returns `COVB` directly; the other functions return `COVB` in `stats.covb`.

`[p,t,r] = linhpytest(...)` also returns the test statistic `t` and the rank `r` of the hypothesis matrix `H`. If `dfe` is `Inf` or is not given, `t*r` is a chi-square statistic with `r` degrees of freedom. If `dfe` is specified as a finite value, `t` is an F statistic with `r` and `dfe` degrees of freedom.

`linhpytest` performs a test based on an asymptotic normal distribution for the parameter estimates. It can be used after any estimation

procedure for which the parameter covariances are available, such as `regstats` or `glmfit`. For linear regression, the p -values are exact. For other procedures, the p -values are approximate, and may be less accurate than other procedures such as those based on a likelihood ratio.

Examples

Fit a multiple linear model to the data in `hald.mat`:

```
load hald
stats = regstats(heat,ingredients,'linear');
beta = stats.beta
beta =
    62.4054
     1.5511
     0.5102
     0.1019
    -0.1441
```

Perform an F -test that the last two coefficients are both 0:

```
SIGMA = stats.covb;
dfe = stats.fstat.dfe;
H = [0 0 0 1 0;0 0 0 0 1];
c = [0;0];
[p,F] = linhpytest(beta,SIGMA,c,H,dfe)
p =
    0.4668
F =
    0.8391
```

See Also

`regstats` | `glmfit` | `robustfit` | `mnrfit` | `nlinfit` | `coxphfit`

linkage

Purpose

Agglomerative hierarchical cluster tree

Syntax

```
Z = linkage(X)
Z = linkage(X,method)
Z = linkage(X,method,metric)
Z = linkage(X,method,pdist_inputs)
Z = linkage(X,method,metric,'savememory',value)
Z = linkage(Y)
Z = linkage(Y,method)
```

Description

`Z = linkage(X)` returns a matrix `Z` that encodes a tree of hierarchical clusters of the rows of the real matrix `X`.

`Z = linkage(X,method)` creates the tree using the specified *method*, where *method* describes how to measure the distance between clusters.

`Z = linkage(X,method,metric)` performs clustering using the distance measure *metric* to compute distances between the rows of `X`.

`Z = linkage(X,method,pdist_inputs)` passes parameters to the `pdist` function, which is the function that computes the distance between rows of `X`.

`Z = linkage(X,method,metric,'savememory',value)` uses a memory-saving algorithm when *value* is 'true', and uses the standard algorithm when *value* is 'false'.

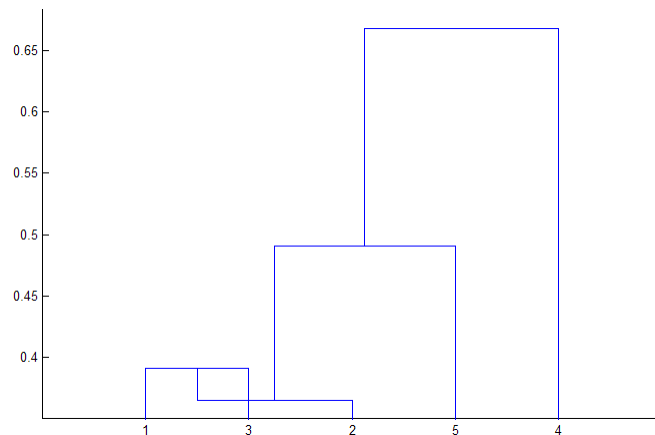
`Z = linkage(Y)` uses a vector representation `Y` of a distance matrix. `Y` can be a distance matrix as computed by `pdist`, or a more general dissimilarity matrix conforming to the output format of `pdist`.

`Z = linkage(Y,method)` creates the tree using the specified *method*, where *method* describes how to measure the distance between clusters.

Tips

- Computing `linkage(Y)` can be slow when `Y` is a vector representation of the distance matrix. For the 'centroid', 'median', and 'ward' methods, `linkage` checks whether `Y` is a Euclidean distance. Avoid this time-consuming check by passing in `X` instead of `Y`.

- The centroid and median methods can produce a cluster tree that is not monotonic. This occurs when the distance from the union of two clusters, r and s , to a third cluster is less than the distance between r and s . In this case, in a dendrogram drawn with the default orientation, the path from a leaf to the root node takes some downward steps. To avoid this, use another method. The following image shows a nonmonotonic cluster tree.



In this case, cluster 1 and cluster 3 are joined into a new cluster, while the distance between this new cluster and cluster 2 is less than the distance between cluster 1 and cluster 3. This leads to a nonmonotonic tree.

- You can provide the output Z to other functions including `dendrogram` to display the tree, `cluster` to assign points to clusters, `inconsistent` to compute inconsistent measures, and `cophenet` to compute the cophenetic correlation coefficient.

Input Arguments

X

Matrix with two or more rows. The rows represent observations, the columns represent categories or dimensions.

method

linkage

Algorithm for computing distance between clusters.

Method	Description
'average'	Unweighted average distance (UPGMA)
'centroid'	Centroid distance (UPGMC), appropriate for Euclidean distances only
'complete'	Furthest distance
'median'	Weighted center of mass distance (WPGMC), appropriate for Euclidean distances only
'single'	Shortest distance
'ward'	Inner squared distance (minimum variance algorithm), appropriate for Euclidean distances only
'weighted'	Weighted average distance (WPGMA)

Default: 'single'

metric

Any distance metric that the `pdist` function accepts.

Metric	Description
'euclidean'	Euclidean distance (default).
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between rows in X is scaled by dividing by the corresponding element of the standard deviation $S = \text{nanstd}(X)$. To specify another value for S, use $D = \text{pdist}(X, \text{'seuclidean'}, S)$.
'cityblock'	City block metric.

Metric	Description
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use $D = \text{pdist}(X, \text{'minkowski'}, P)$, where P is a scalar
'chebychev'	Chebychev distance (maximum coordinate difference).
'mahalanobis'	Mahalanobis distance, using the sample covariance of X as computed by <code>nancov</code> . To compute the distance with a different covariance, use $D = \text{pdist}(X, \text{'mahalanobis'}, C)$, where the matrix C is symmetric and positive definite.
'cosine'	One minus the cosine of the included angle between points (treated as vectors).
'correlation'	One minus the sample correlation between points (treated as sequences of values).
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
'hamming'	Hamming distance, which is the percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ.
custom distance function	<p>A distance function specified using @: $D = \text{pdist}(X, @\text{distfun})$</p> <p>A distance function must be of form</p> $d2 = \text{distfun}(XI, XJ)$ <p>taking as arguments a 1-by-n vector XI, corresponding to a single row of X, and an $m2$-by-n matrix XJ, corresponding to multiple rows of X. <code>distfun</code> must accept a matrix XJ</p>

linkage

Metric	Description
	with an arbitrary number of rows. <code>distfun</code> must return an $m2$ -by-1 vector of distances <code>d2</code> , whose k th element is the distance between <code>XI</code> and <code>XJ(k, :)</code> .

Default: 'euclidean'

pdist_inputs

A cell array of parameters accepted by the `pdist` function. For example, to set the *metric* to `minkowski` and use an exponent of 5, set `pdist_inputs` to `{'minkowski',5}`.

savememory

A string, either 'on' or 'off'. When applicable, the 'on' setting causes `linkage` to construct clusters without computing the distance matrix. `savememory` is applicable when:

- `linkage` is 'centroid', 'median', or 'ward'
- `distance` is 'euclidean' (default)

When `savememory` is 'on', `linkage` run time is proportional to the number of dimensions (number of columns of `X`). When `savememory` is 'off', `linkage` memory requirement is proportional to N^2 , where N is the number of observations. So choosing the best (least-time) setting for `savememory` depends on the problem dimensions, number of observations, and available memory. The default `savememory` setting is a rough approximation of an optimal setting.

Default: 'on' when `X` has 20 columns or fewer, or the computer does not have enough memory to store the distance matrix; otherwise 'off'

Y

A vector of distances with the same format as the output of the `pdist` function:

- A row vector of length $m(m-1)/2$, corresponding to pairs of observations in a matrix X with m rows
- Distances arranged in the order $(2,1), (3,1), \dots, (m,1), (3,2), \dots, (m,2), \dots, (m,m-1)$

Y can be a more general dissimilarity matrix conforming to the output format of `pdist`.

Output Arguments

Z

Z is a $(m-1)$ -by-3 matrix, where m is the number of observations in the original data. Columns 1 and 2 of Z contain cluster indices linked in pairs to form a binary tree. The leaf nodes are numbered from 1 to m . Leaf nodes are the singleton clusters from which all higher clusters are built. Each newly-formed cluster, corresponding to row $Z(I, :)$, is assigned the index $m+I$. $Z(I, 1:2)$ contains the indices of the two component clusters that form cluster $m+I$. There are $m-1$ higher clusters which correspond to the interior nodes of the clustering tree. $Z(I, 3)$ contains the linkage distances between the two clusters merged in row $Z(I, :)$.

For example, suppose there are 30 initial nodes and at step 12 cluster 5 and cluster 7 are combined. Suppose their distance at that time is 1.5. Then $Z(12, :)$ will be $[5, 7, 1.5]$. The newly formed cluster will have index $12 + 30 = 42$. If cluster 42 appears in a later row, it means the cluster created at step 12 is being combined into some larger cluster.

Definitions

Linkages

The following notation is used to describe the linkages used by the various methods:

- Cluster r is formed from clusters p and q .
- n_r is the number of objects in cluster r .
- x_{ri} is the i th object in cluster r .

linkage

- *Single linkage*, also called *nearest neighbor*, uses the smallest distance between objects in the two clusters:

$$d(r, s) = \min(\text{dist}(x_{ri}, x_{sj}), i \in (1, \dots, n_r), j \in (1, \dots, n_s))$$

- *Complete linkage*, also called *furthest neighbor*, uses the largest distance between objects in the two clusters:

$$d(r, s) = \max(\text{dist}(x_{ri}, x_{sj}), i \in (1, \dots, n_r), j \in (1, \dots, n_s))$$

- *Average linkage* uses the average distance between all pairs of objects in any two clusters:

$$d(r, s) = \frac{1}{n_r n_s} \sum_{i=1}^{n_r} \sum_{j=1}^{n_s} \text{dist}(x_{ri}, x_{sj})$$

- *Centroid linkage* uses the Euclidean distance between the centroids of the two clusters:

$$d(r, s) = \|\bar{x}_r - \bar{x}_s\|_2$$

where

$$\bar{x}_r = \frac{1}{n_r} \sum_{i=1}^{n_r} x_{ri}$$

- *Median linkage* uses the Euclidean distance between weighted centroids of the two clusters,

$$d(r, s) = \|\tilde{x}_r - \tilde{x}_s\|_2$$

where \tilde{x}_r and \tilde{x}_s are weighted centroids for the clusters r and s . If cluster r was created by combining clusters p and q , \tilde{x}_r is defined recursively as

$$\tilde{x}_r = \frac{1}{2}(\tilde{x}_p + \tilde{x}_q)$$

- *Ward's linkage* uses the incremental sum of squares; that is, the increase in the total within-cluster sum of squares as a result of joining two clusters. The within-cluster sum of squares is defined as the sum of the squares of the distances between all objects in the cluster and the centroid of the cluster. The sum of squares measure is equivalent to the following distance measure $d(r,s)$, which is the formula linkage uses:

$$d(r,s) = \sqrt{\frac{2n_r n_s}{(n_r + n_s)}} \|\bar{x}_r - \bar{x}_s\|_2,$$

where

- $\|\cdot\|_2$ is Euclidean distance
- \bar{x}_r and \bar{x}_s are the centroids of clusters r and s
- n_r and n_s are the number of elements in clusters r and s

In some references the Ward linkage does not use the factor of 2 multiplying $n_r n_s$. The linkage function uses this factor so the distance between two singleton clusters is the same as the Euclidean distance.

- *Weighted average linkage* uses a recursive definition for the distance between two clusters. If cluster r was created by combining clusters p and q , the distance between r and another cluster s is defined as the average of the distance between p and s and the distance between q and s :

$$d(r,s) = \frac{(d(p,s) + d(q,s))}{2}$$

linkage

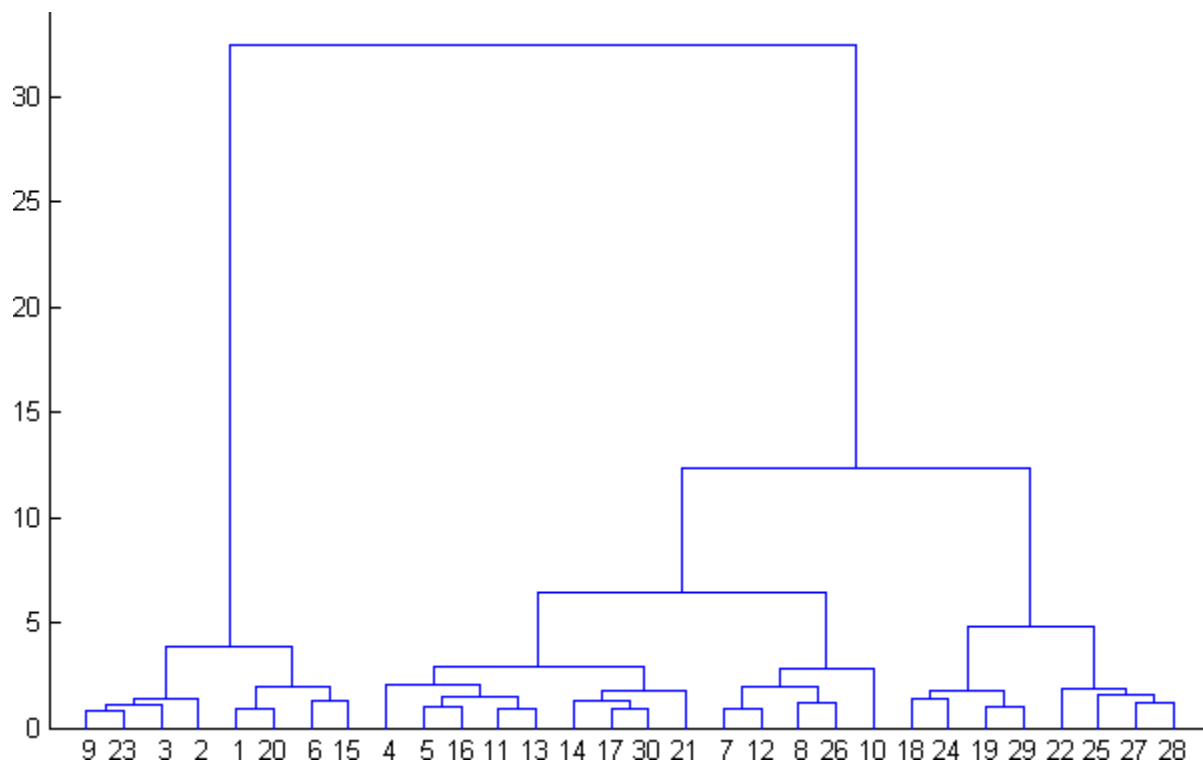
Examples

Compute four clusters of the Fisher iris data using Ward linkage and ignoring species information, and see how the cluster assignments correspond to the three species.

```
load fisheriris
Z = linkage(meas,'ward','euclidean');
c = cluster(Z,'maxclust',4);
crosstab(c,species)
firstfive = Z(1:5,:) % first 5 rows of Z
dendrogram(Z)
```

```
ans =
     0     25     1
     0     24    14
     0      1    35
    50      0     0
```

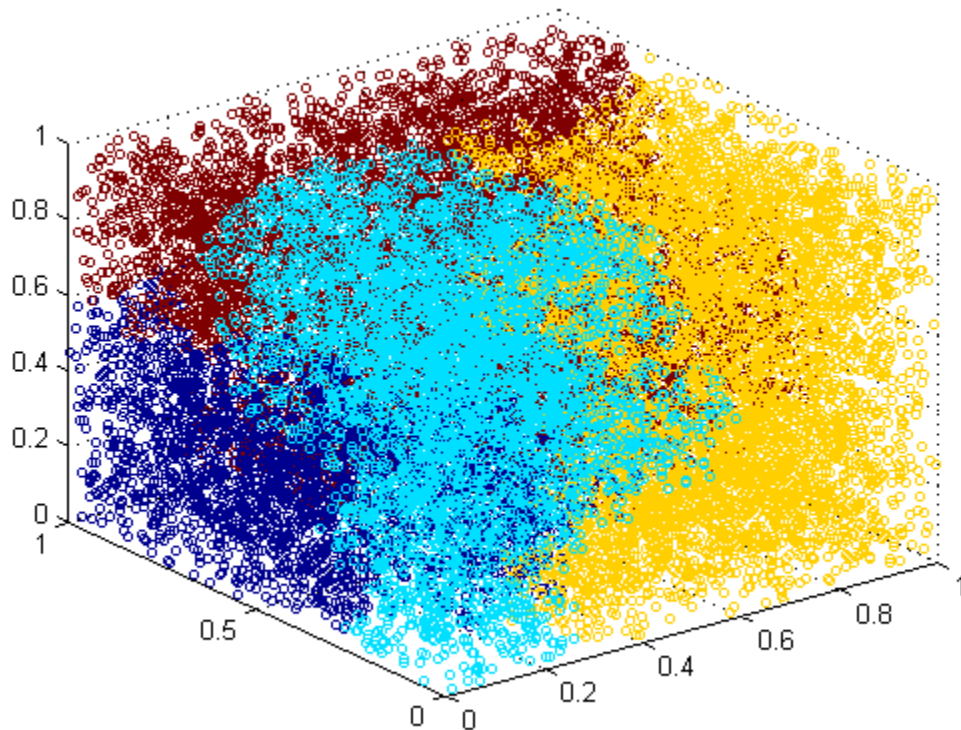
```
firstfive =
 102.0000  143.0000         0
   8.0000  40.0000    0.1000
   1.0000  18.0000    0.1000
  10.0000  35.0000    0.1000
 129.0000 133.0000    0.1000
```



Create a hierarchical cluster tree for a data with 20000 observations using Ward's linkage. If you set `savememory` to `'off'`, you can get an out-of-memory error if your machine doesn't have enough memory to hold the distance matrix. Cluster the data into four groups and plot the result.

```
X = rand(20000,3);  
Z = linkage(X,'ward','euclidean','savememory','on');  
c = cluster(Z,'maxclust',4);  
scatter3(X(:,1),X(:,2),X(:,3),10,c)
```

linkage



See Also

[cluster](#) | [clusterdata](#) | [cophenet](#) | [dendrogram](#) | [inconsistent](#) | [kmeans](#) | [pdist](#) | [silhouette](#) | [squareform](#)

Purpose

Lognormal cumulative distribution function

Syntax

`P = logncdf(X,mu,sigma)`
`[P,PLO,PUP] = logncdf(X,mu,sigma,pcov,alpha)`

Description

`P = logncdf(X,mu,sigma)` returns values at `X` of the lognormal cdf with distribution parameters `mu` and `sigma`. `mu` and `sigma` are the mean and standard deviation, respectively, of the associated normal distribution. `X`, `mu`, and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input for `X`, `mu`, or `sigma` is expanded to a constant array with the same dimensions as the other inputs.

`[P,PLO,PUP] = logncdf(X,mu,sigma,pcov,alpha)` returns confidence bounds for `P` when the input parameters `mu` and `sigma` are estimates. `pcov` is the covariance matrix of the estimated parameters. `alpha` specifies 100(1 - `alpha`)% confidence bounds. The default value of `alpha` is 0.05. `PLO` and `PUP` are arrays of the same size as `P` containing the lower and upper confidence bounds.

`logncdf` computes confidence bounds for `P` using a normal approximation to the distribution of the estimate

$$\frac{X - \hat{\mu}}{\hat{\sigma}}$$

and then transforming those bounds to the scale of the output `P`. The computed bounds give approximately the desired confidence level when you estimate `mu`, `sigma`, and `pcov` from large samples, but in smaller samples other methods of computing the confidence bounds might be more accurate.

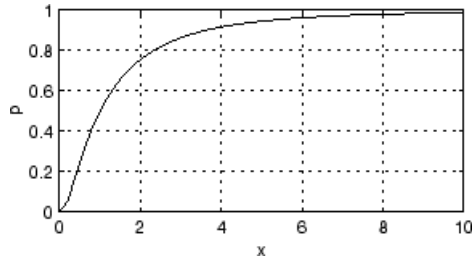
The lognormal cdf is

$$p = F(x | \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^x e^{-\frac{(\ln(t)-\mu)^2}{2\sigma^2}} \frac{1}{t} dt$$

logncdf

Examples

```
x = (0:0.2:10);  
y = logncdf(x,0,1);  
plot(x,y); grid;  
xlabel('x'); ylabel('p');
```



References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 102–105.

See Also

[cdf](#) | [lognpdf](#) | [logninv](#) | [lognstat](#) | [lognfit](#) | [lognlike](#) | [lognrnd](#)

How To

- “Lognormal Distribution” on page B-64

Purpose

Lognormal parameter estimates

Syntax

```
parmhat = lognfit(data)
[parmhat,parmci] = lognfit(data)
[parmhat,parmci] = lognfit(data,alpha)
[...] = lognfit(data,alpha,censoring)
[...] = lognfit(data,alpha,censoring,freq)
[...] = lognfit(data,alpha,censoring,freq,options)
```

Description

`parmhat = lognfit(data)` returns a vector of maximum likelihood estimates `parmhat(1) = mu` and `parmhat(2) = sigma` of parameters for a lognormal distribution fitting data. `mu` and `sigma` are the mean and standard deviation, respectively, of the associated normal distribution.

`[parmhat,parmci] = lognfit(data)` returns 95% confidence intervals for the parameter estimates `mu` and `sigma` in the 2-by-2 matrix `parmci`. The first column of the matrix contains the lower and upper confidence bounds for parameter `mu`, and the second column contains the confidence bounds for parameter `sigma`.

`[parmhat,parmci] = lognfit(data,alpha)` returns $100(1 - \alpha)\%$ confidence intervals for the parameter estimates, where `alpha` is a value in the range (0 1) specifying the width of the confidence intervals. By default, `alpha` is 0.05, which corresponds to 95% confidence intervals.

`[...] = lognfit(data,alpha,censoring)` accepts a Boolean vector `censoring`, of the same size as `data`, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.

`[...] = lognfit(data,alpha,censoring,freq)` accepts a frequency vector, `freq`, of the same size as `data`. Typically, `freq` contains integer frequencies for the corresponding elements in `data`, but can contain any nonnegative values. Pass in `[]` for `alpha`, `censoring`, or `freq` to use their default values.

`[...] = lognfit(data,alpha,censoring,freq,options)` accepts a structure, `options`, that specifies control parameters for the iterative algorithm the function uses to compute maximum likelihood estimates when there is censoring. The lognormal fit function accepts an `options`

lognfit

structure which can be created using the function `statset`. Enter `statset('lognfit')` to see the names and default values of the parameters that `lognfit` accepts in the `options` structure. See the reference page for `statset` for more information about these options.

Note With no censoring, `lognfit` computes `sigma` using the square root of the unbiased estimator of the variance. With censoring, `sigma` is the maximum likelihood estimate.

Examples

This example generates 100 independent samples of lognormally distributed data with $\mu = 0$ and $\sigma = 3$. `parmhat` estimates μ and σ and `parmci` gives 99% confidence intervals around `parmhat`. Notice that `parmci` contains the true values of μ and σ .

```
data = lognrnd(0,3,100,1);
[parmhat,parmci] = lognfit(data,0.01)
parmhat =
    -0.2480    2.8902
parmci =
    -1.0071    2.4393
     0.5111    3.5262
```

See Also

`mle` | `lognlike` | `lognpdf` | `logncdf` | `logninv` | `lognstat` | `lognrnd`

How To

- “Lognormal Distribution” on page B-64

Purpose Lognormal inverse cumulative distribution function

Syntax `X = logninv(P,mu,sigma)`
`[X,XLO,XUP] = logninv(P,mu,sigma,pcov,alpha)`

Description `X = logninv(P,mu,sigma)` returns values at `P` of the inverse lognormal cdf with distribution parameters `mu` and `sigma`. `mu` and `sigma` are the mean and standard deviation, respectively, of the associated normal distribution. `mu` and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `X`. A scalar input for `P`, `mu`, or `sigma` is expanded to a constant array with the same dimensions as the other inputs.

`[X,XLO,XUP] = logninv(P,mu,sigma,pcov,alpha)` returns confidence bounds for `X` when the input parameters `mu` and `sigma` are estimates. `pcov` is the covariance matrix of the estimated parameters. `alpha` specifies `100(1 - alpha)%` confidence bounds. The default value of `alpha` is `0.05`. `XLO` and `XUP` are arrays of the same size as `X` containing the lower and upper confidence bounds.

`logninv` computes confidence bounds for `P` using a normal approximation to the distribution of the estimate

$$\hat{\mu} + \hat{\sigma}q$$

where q is the P th quantile from a normal distribution with mean 0 and standard deviation 1. The computed bounds give approximately the desired confidence level when you estimate `mu`, `sigma`, and `pcov` from large samples, but in smaller samples other methods of computing the confidence bounds might be more accurate.

The lognormal inverse function is defined in terms of the lognormal cdf as

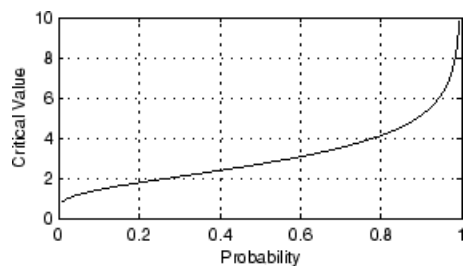
$$x = F^{-1}(p | \mu, \sigma) = \{x : F(x | \mu, \sigma) = p\}$$

where

$$p = F(x | \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_0^x e^{-\frac{(\ln(t)-\mu)^2}{2\sigma^2}} dt$$

Examples

```
p = (0.005:0.01:0.995);  
crit = logninv(p,1,0.5);  
plot(p,crit)  
xlabel('Probability'); ylabel('Critical Value'); grid
```



References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. Hoboken, NJ: Wiley-Interscience, 2000. pp. 102–105.

See Also

icdf | logncdf | lognpdf | lognstat | lognfit | lognlike | lognrnd

How To

• “Lognormal Distribution” on page B-64

Purpose	Lognormal negative log-likelihood
Syntax	<pre>nlogL = lognlike(params,data) [nlogL,avar] = lognlike(params,data) [...] = lognlike(params,data,censoring) [...] = lognlike(params,data,censoring,freq)</pre>
Description	<p><code>nlogL = lognlike(params,data)</code> returns the negative log-likelihood of data for the lognormal distribution with parameters <code>params</code>. <code>params(1)</code> is the mean of the associated normal distribution, <code>mu</code>, and <code>params(2)</code> is the standard deviation of the associated normal distribution, <code>sigma</code>. The values of <code>mu</code> and <code>sigma</code> are scalars, and the output <code>nlogL</code> is a scalar.</p> <p><code>[nlogL,avar] = lognlike(params,data)</code> returns the inverse of Fisher's information matrix. If the input parameter value in <code>params</code> is the maximum likelihood estimate, <code>avar</code> is its asymptotic variance. <code>avar</code> is based on the observed Fisher's information, not the expected information.</p> <p><code>[...] = lognlike(params,data,censoring)</code> accepts a Boolean vector, <code>censoring</code>, of the same size as <code>data</code>, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.</p> <p><code>[...] = lognlike(params,data,censoring,freq)</code> accepts a frequency vector, <code>freq</code>, of the same size as <code>data</code>. The vector <code>freq</code> typically contains integer frequencies for the corresponding elements in <code>data</code>, but can contain any nonnegative values. Pass in <code>[]</code> for <code>censoring</code> to use its default value.</p>
See Also	<code>lognfit</code> <code>lognpdf</code> <code>logncdf</code> <code>logninv</code> <code>lognstat</code> <code>lognrnd</code>
How To	<ul style="list-style-type: none">• “Lognormal Distribution” on page B-64

lognpdf

Purpose Lognormal probability density function

Syntax `Y = lognpdf(X,mu,sigma)`

Description `Y = lognpdf(X,mu,sigma)` returns values at `X` of the lognormal pdf with distribution parameters `mu` and `sigma`. `mu` and `sigma` are the mean and standard deviation, respectively, of the associated normal distribution. `X`, `mu`, and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `Y`. A scalar input for `X`, `mu`, or `sigma` is expanded to a constant array with the same dimensions as the other inputs.

The lognormal pdf is

$$y = f(x | \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

The normal and lognormal distributions are closely related. If X is distributed lognormally with parameters μ and σ , then $\log(X)$ is distributed normally with mean μ and standard deviation σ .

The mean m and variance v of a lognormal random variable are functions of μ and σ that can be calculated with the `lognstat` function. They are:

$$m = \exp\left(\mu + \sigma^2 / 2\right)$$

$$v = \exp\left(2\mu + \sigma^2\right)\left(\exp\left(\sigma^2\right) - 1\right)$$

A lognormal distribution with mean m and variance v has parameters

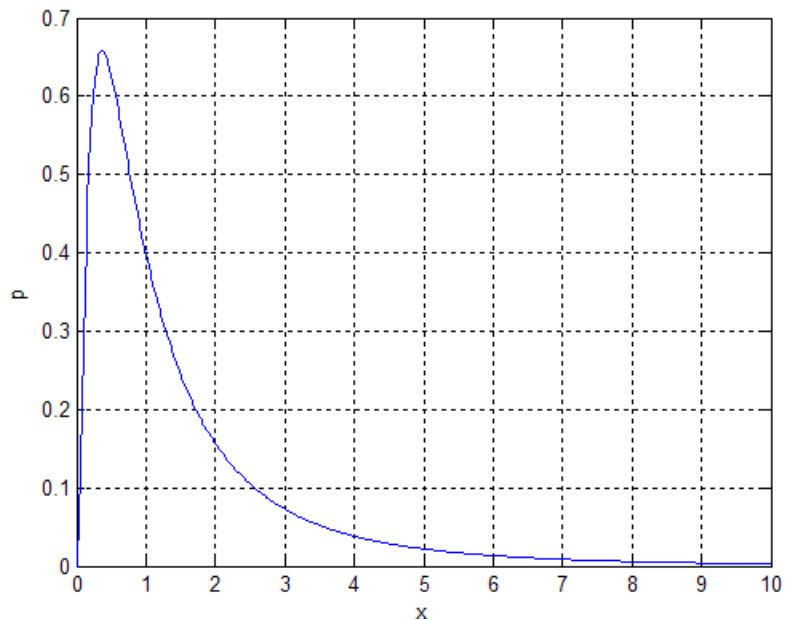
$$\mu = \log\left(m^2 / \sqrt{v + m^2}\right)$$

$$\sigma = \sqrt{\log\left(v / m^2 + 1\right)}$$

The lognormal distribution is applicable when the quantity of interest must be positive, since $\log(X)$ exists only when X is positive.

Examples

```
x = (0:0.02:10);  
y = lognpdf(x,0,1);  
plot(x,y); grid;  
xlabel('x'); ylabel('p')
```



References

[1] Mood, A. M., F. A. Graybill, and D. C. Boes. *Introduction to the Theory of Statistics*. 3rd ed., New York: McGraw-Hill, 1974. pp. 540–541.

See Also

pdf | logncdf | logninv | lognstat | lognfit | lognlike | lognrnd

How To

- “Lognormal Distribution” on page B-64

lognrnd

Purpose Lognormal random numbers

Syntax
R = lognrnd(mu,sigma)
R = lognrnd(mu,sigma,m,n,...)
R = lognrnd(mu,sigma,[m,n,...])

Description R = lognrnd(mu,sigma) returns an array of random numbers generated from the lognormal distribution with parameters mu and sigma. mu and sigma are the mean and standard deviation, respectively, of the associated normal distribution. mu and sigma can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of R. A scalar input for mu or sigma is expanded to a constant array with the same dimensions as the other input.

R = lognrnd(mu,sigma,m,n,...) or R = lognrnd(mu,sigma,[m,n,...]) generates an m-by-n-by-... array. The mu, sigma parameters can each be scalars or arrays of the same size as R.

The normal and lognormal distributions are closely related. If X is distributed lognormally with parameters μ and σ , then $\log(X)$ is distributed normally with mean μ and standard deviation σ .

The mean m and variance v of a lognormal random variable are functions of μ and σ that can be calculated with the lognstat function. They are:

$$m = \exp\left(\mu + \sigma^2 / 2\right)$$
$$v = \exp\left(2\mu + \sigma^2\right)\left(\exp\left(\sigma^2\right) - 1\right)$$

A lognormal distribution with mean m and variance v has parameters

$$\mu = \log\left(m^2 / \sqrt{v + m^2}\right)$$
$$\sigma = \sqrt{\log\left(v / m^2 + 1\right)}$$

Examples

Generate one million lognormally distributed random numbers with mean 1 and variance 2:

```
m = 1;  
v = 2;  
mu = log((m^2)/sqrt(v+m^2));  
sigma = sqrt(log(v/(m^2)+1));
```

```
[M,V]= lognstat(mu,sigma)
```

```
M =  
    1  
V =  
    2.0000
```

```
X = lognrnd(mu,sigma,1,1e6);
```

```
MX = mean(X)
```

```
MX =  
    0.9974
```

```
VX = var(X)
```

```
VX =  
    1.9776
```

References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. Hoboken, NJ: Wiley-Interscience, 2000. pp. 102–105.

See Also

random | lognpdf | logncdf | logninv | lognstat | lognfit | lognlike | normrnd

How To

- “Lognormal Distribution” on page B-64

lognstat

Purpose Lognormal mean and variance

Syntax `[M,V] = lognstat(mu,sigma)`

Description `[M,V] = lognstat(mu,sigma)` returns the mean of and variance of the lognormal distribution with parameters `mu` and `sigma`. `mu` and `sigma` are the mean and standard deviation, respectively, of the associated normal distribution. `mu` and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `M` and `V`. A scalar input for `mu` or `sigma` is expanded to a constant array with the same dimensions as the other input.

The normal and lognormal distributions are closely related. If X is distributed lognormally with parameters μ and σ , then $\log(X)$ is distributed normally with mean μ and standard deviation σ .

The mean m and variance v of a lognormal random variable are functions of μ and σ that can be calculated with the `lognstat` function. They are:

$$m = \exp\left(\mu + \sigma^2 / 2\right)$$
$$v = \exp\left(2\mu + \sigma^2\right)\left(\exp\left(\sigma^2\right) - 1\right)$$

A lognormal distribution with mean m and variance v has parameters

$$\mu = \log\left(m^2 / \sqrt{v + m^2}\right)$$
$$\sigma = \sqrt{\log\left(v / m^2 + 1\right)}$$

Examples Generate one million lognormally distributed random numbers with mean 1 and variance 2:

```
m = 1;  
v = 2;
```



```
mu = log((m^2)/sqrt(v+m^2));  
sigma = sqrt(log(v/(m^2)+1));
```

```
[M,V]= lognstat(mu,sigma)
```

```
M =
```

```
1
```

```
V =
```

```
2.0000
```

```
X = lognrnd(mu,sigma,1,1e6);
```

```
MX = mean(X)
```

```
MX =
```

```
0.9974
```

```
VX = var(X)
```

```
VX =
```

```
1.9776
```

References

[1] Mood, A. M., F. A. Graybill, and D. C. Boes. *Introduction to the Theory of Statistics*. 3rd ed., New York: McGraw-Hill, 1974. pp. 540–541.

See Also

lognpdf | logncdf | logninv | lognfit | lognlike | lognrnd

How To

• “Lognormal Distribution” on page B-64

CompactClassificationDiscriminant.logP

Purpose Log of the unconditional probability density

Syntax `lp = logP(obj, Xnew)`

Description `lp = logP(obj, Xnew)` returns the log of the unconditional probability density of each row of `Xnew`, computed using the discriminant analysis model `obj`.

Input Arguments

obj
Discriminant analysis classifier, produced using `ClassificationDiscriminant.fit`.

Xnew
Matrix where each row represents an observation, and each column represents a predictor. The number of columns in `Xnew` must equal the number of predictors in `obj`.

Output Arguments

lp
Column vector with the same number of rows as `Xnew`. Each entry is the logarithm of the unconditional probability density of the corresponding row of `Xnew`.

Definitions **Unconditional Probability Density**

The unconditional probability density of a point x of a discriminant analysis model is

$$P(x) = \sum_{k=1}^K P(x, k),$$

where $P(x, k)$ is the conditional density of the model at x for class k , when the total number of classes is K .

The conditional density $P(x, k)$ is

$$P(x,k) = P(k)P(x|k),$$

where $P(k)$ is the prior probability of class k , and $P(x|k)$ is the conditional density of x given class k . The conditional density function of the multivariate normal with mean μ_k and covariance Σ_k at a point x is

$$P(x|k) = \frac{1}{(2\pi|\Sigma_k|)^{1/2}} \exp\left(-\frac{1}{2}(x-\mu_k)^T \Sigma_k^{-1}(x-\mu_k)\right),$$

where $|\Sigma_k|$ is the determinant of Σ_k , and Σ_k^{-1} is the inverse matrix.

Examples

logP Calculation

Construct a discriminant analysis classifier for the Fisher iris data, and examine its prediction for an average measurement.

Load the Fisher iris data and construct a default discriminant analysis classifier.

```
load fisheriris
mdl = ClassificationDiscriminant.fit(meas,species);
```

Find the log probability of the discriminant model applied to an average iris.

```
logpaverage = logP(mdl,mean(meas))
```

```
logpaverage =
```

```
-1.7254
```

See Also

CompactClassificationDiscriminant | mahal |

Concepts

- “Discriminant Analysis” on page 12-3

ClassificationKNN.loss

Purpose Loss of k -nearest neighbor classifier

Syntax
`L = loss mdl, X, Y`
`L = loss mdl, X, Y, Name, Value`

Description
`L = loss mdl, X, Y` returns a scalar representing how well `mdl` classifies the data in `X`, when `Y` contains the true classifications.
`L = loss mdl, X, Y, Name, Value` returns the loss with additional options specified by one or more `Name, Value` pair arguments.

Input Arguments

mdl
k-nearest neighbor classifier, created by `ClassificationKNN.fit`.

X
Matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

Y
Grouping variables of response values with the same number of elements (rows) as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

lossfun

Function handle or string representing a loss function. The built-in loss functions are:

- 'binodeviance' — See “Loss Functions” on page 20-1203.

- 'exponential' — See “Loss Functions” on page 20-1203.
- 'classiferror' — Fraction of misclassified observations. See “Loss Functions” on page 20-1203.
- 'mincost' — Smallest misclassification cost as given by the `mdl.Cost` matrix. See “Loss Functions” on page 20-1203.

You can write your own loss function using the syntax described in “Loss Functions” on page 20-1203.

Default: 'mincost'

weights

Numeric vector of length N , where N is the number of rows of X . `weights` are nonnegative. When you supply `weights`, `loss` computes weighted classification loss.

Default: `ones(N,1)`

Output Arguments

L

Classification error, a scalar. The meaning of the error depends on the values in `weights` and `lossfun`. See “Classification Error” on page 20-1209.

Definitions

Classification Error

The default classification error is the fraction of data X that `mdl` misclassifies, where Y represents the true classifications.

The weighted classification error is the sum of weight i times the Boolean value that is 1 when `mdl` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

ClassificationKNN.loss

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

- 'classiferror' — Predict the label with the largest posterior probability. The loss is then the fraction of misclassified observations.
- 'mincost' — Predict the label with the smallest expected misclassification cost, with expectation taken over the posterior probability, and cost as given by the `Cost` property of the classifier (a matrix). The loss is then the true misclassification cost averaged over the observations.

To write your own loss function, create a function file in this form:

```
function loss = lossfun(C,S,W,COST)
```

- `N` is the number of rows of `X`.
- `K` is the number of classes in the classifier, represented in the `ClassNames` property.
- `C` is an `N`-by-`K` logical matrix, with one true per row for the true class. The index for each class is its position in the `ClassNames` property.
- `S` is an `N`-by-`K` numeric matrix. `S` is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from `predict`.
- `W` is a numeric vector with `N` elements, the observation weights. If you pass `W`, the elements are normalized to sum to the prior probabilities in the respective classes.

- COST is a K-by-K numeric matrix of misclassification costs. For example, you can use `COST = ones(K) - eye(K)`, which means a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

True Misclassification Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation.

You can set the true misclassification cost per class in the `Cost` name-value pair when you run `ClassificationKNN.fit`. `Cost(i,j)` is the cost of classifying an observation into class `j` if its true class is `i`. By default, `Cost(i,j)=1` if `i~=j`, and `Cost(i,j)=0` if `i=j`. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

Expected Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation. The third output of `predict` is the expected misclassification cost per observation.

Suppose you have `Nobs` observations that you want to classify with a trained classifier `mdl`. Suppose you have `K` classes. You place the observations into a matrix `Xnew` with one observation per row. The command

```
[label,score,cost] = predict(mdl,Xnew)
```

returns, among other outputs, a `cost` matrix of size `Nobs`-by-`K`. Each row of the `cost` matrix contains the expected (average) cost of classifying the observation into each of the `K` classes. `cost(n,k)` is

ClassificationKNN.loss

$$\sum_{i=1}^K \hat{P}(i | X_{new}(n)) C(k | i),$$

where

- K is the number of classes.
- $\hat{P}(i | X_{new}(n))$ is the posterior probability of class i for observation $X_{new}(n)$.
- $C(k | i)$ is the true misclassification cost of classifying an observation as k when its true class is i .

Examples

Loss Calculation

Construct a k -nearest neighbor classifier for the Fisher iris data, where $k = 5$.

Load the data.

```
load fisheriris
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(meas,species,'NumNeighbors',5);
```

Examine the loss of the classifier for a mean observation classified 'versicolor'.

```
X = mean(meas);  
Y = {'versicolor'};  
L = loss(mdl,X,Y)
```

```
L =
```

```
0
```


The classifier has no doubt that 'versicolor' is the correct classification (all five nearest neighbors classify as 'versicolor').

See Also

ClassificationKNN | edge | margin |

Related Examples

- “Examine the Quality of a KNN Classifier” on page 13-26
- “Predict Classification Based on a KNN Classifier” on page 13-27
- “Modify a KNN Classifier” on page 13-27

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

CompactClassificationDiscriminant.loss

Purpose Classification error

Syntax `L = loss(obj,X,Y)`
`L = loss(obj,X,Y,Name,Value)`

Description `L = loss(obj,X,Y)` returns a scalar representing how well `obj` classifies the data in `X`, when `Y` contains the true classifications.

`L = loss(obj,X,Y,Name,Value)` returns the loss with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

obj
Discriminant analysis classifier of class `ClassificationDiscriminant` or `CompactClassificationDiscriminant`, typically constructed with `ClassificationDiscriminant.fit`.

X

Matrix where each row represents an observation, and each column represents a predictor. The number of columns in `X` must equal the number of predictors in `obj`.

Y

Class labels, with the same data type as exists in `obj`. The number of elements of `Y` must equal the number of rows of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

lossfun

Function handle or string representing a loss function. Built-in loss functions:

- 'binodeviance' — See “Loss Functions” on page 20-1209.
- 'classiferror' — Fraction of misclassified observations. See “Loss Functions” on page 20-1209.
- 'exponential' — See “Loss Functions” on page 20-1209.
- 'mincost' — Smallest misclassification cost as given by the `obj.Cost` matrix. See “Loss Functions” on page 20-1209.

You can write your own loss function using the syntax described in “Loss Functions” on page 20-1209.

Default: 'mincost'

weights

Numeric vector of length N , where N is the number of rows of X . `weights` are nonnegative. When you supply `weights`, `loss` computes weighted classification loss.

Default: `ones(N,1)`

Output Arguments

L

Classification error, a scalar. The meaning of the error depends on the values in `weights` and `lossfun`. See “Classification Error” on page 20-1209.

Definitions

Classification Error

The default classification error is the fraction of data X that `obj` misclassifies, where Y represents the true classifications.

Weighted classification error is the sum of weight i times the Boolean value that is 1 when `obj` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

CompactClassificationDiscriminant.loss

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

- 'classiferror' — Predict the label with the largest posterior probability. The loss is then the fraction of misclassified observations.
- 'mincost' — Predict the label with the smallest expected misclassification cost, with expectation taken over the posterior probability, and cost as given by the Cost property of the classifier (a matrix). The loss is then the true misclassification cost averaged over the observations.

To write your own loss function, create a function file in this form:

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of X.
- K is the number of classes in the classifier, represented in the ClassNames property.
- C is an N-by-K logical matrix, with one true per row for the true class. The index for each class is its position in the ClassNames property.
- S is an N-by-K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from predict.
- W is a numeric vector with N elements, the observation weights. If you pass W, the elements are normalized to sum to the prior probabilities in the respective classes.

CompactClassificationDiscriminant.loss

- COST is a K-by-K numeric matrix of misclassification costs. For example, you can use $\text{COST} = \text{ones}(K) - \text{eye}(K)$, which means a cost of 0 for correct classification, and 1 for misclassification.
- The output loss should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

Posterior Probability

The posterior probability that a point z belongs to class j is the product of the prior probability and the multivariate normal density. The density function of the multivariate normal with mean μ_j and covariance Σ_j at a point z is

$$P(x | k) = \frac{1}{(2\pi |\Sigma_k|)^{1/2}} \exp\left(-\frac{1}{2}(x - \mu_k)^T \Sigma_k^{-1} (x - \mu_k)\right),$$

where $|\Sigma_k|$ is the determinant of Σ_k , and Σ_k^{-1} is the inverse matrix.

Let $P(k)$ represent the prior probability of class k . Then the posterior probability that an observation x is of class k is

$$\hat{P}(k | x) = \frac{P(x | k)P(k)}{P(x)},$$

where $P(x)$ is a normalization constant, the sum over k of $P(x | k)P(k)$.

Prior Probability

The prior probability is one of three choices:

- 'uniform' — The prior probability of class k is one over the total number of classes.
- 'empirical' — The prior probability of class k is the number of training samples of class k divided by the total number of training samples.

CompactClassificationDiscriminant.loss

- Custom — The prior probability of class k is the k th element of the prior vector. See `ClassificationDiscriminant.fit`.

After creating a classifier `obj`, you can set the prior by dot addressing:

```
obj.Prior = v;
```

where `v` is a vector of positive elements representing the frequency with which each element occurs. You do not need to retrain the classifier when you set a new prior.

Cost

The matrix of expected costs per observation is defined in “Cost” on page 12-8.

Examples

Compute the resubstituted classification error for the Fisher iris data:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
L = loss(obj,meas,species)
```

```
L =
    0.0200
```

See Also

`ClassificationDiscriminant` | `edge` | `margin` | `predict`

How To

- “Discriminant Analysis” on page 12-3

CompactClassificationEnsemble.loss

Purpose

Classification error

Syntax

```
L = loss(ens,X,Y)
L = loss(ens,X,Y,Name,Value)
```

Description

`L = loss(ens,X,Y)` returns the classification error for ensemble `ens` computed using matrix of predictors `X` and true class labels `Y`.

`L = loss(ens,X,Y,Name,Value)` computes classification error with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

Classification ensemble created with `fitensemble`, or a compact classification ensemble created with `compact`.

X

Matrix of data to classify. Each row of `X` represents one observation, and each column represents one predictor. `X` must have the same number of columns as the data used to train `ens`. `X` should have the same number of rows as the number of elements in `Y`.

Y

Classification of `X`. `Y` should be of the same type as the classification used to train `ens`, and its number of elements should equal the number of rows of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

CompactClassificationEnsemble.loss

Indices of weak learners in the ensemble ranging from 1 to `ens.NTrained`. `loss` uses only these learners for calculating loss.

Default: `1:NTrained`

lossfun

Function handle or string representing a loss function. Built-in loss functions:

- `'binodeviance'` — See “Loss Functions” on page 20-1215
- `'classiferror'` — Fraction of misclassified data
- `'exponential'` — See “Loss Functions” on page 20-1215

You can write your own loss function in the syntax described in “Loss Functions” on page 20-1215.

Default: `'classiferror'`

mode

String representing the meaning of the output `L`:

- `'ensemble'` — `L` is a scalar value, the loss for the entire ensemble.
- `'individual'` — `L` is a vector with one element per trained learner.
- `'cumulative'` — `L` is a vector in which element `J` is obtained by using learners `1:J` from the input list of learners.

Default: `'ensemble'`

UseObsForLearner

A logical matrix of size `N-by-T`, where:

- N is the number of rows of X .
- T is the number of weak learners in `ens`.

When `UseObsForLearner(i, j)` is `true`, learner j is used in predicting the class of row i of X .

Default: `true(N, T)`

weights

Vector of observation weights, with nonnegative entries. The length of `weights` must equal the number of rows in X .

Default: `ones(size(X, 1), 1)`

Output Arguments

L

Loss, by default the fraction of misclassified data. `L` can be a vector, and can mean different things, depending on the name-value pair settings.

Definitions

Classification Error

The default classification error is the fraction of the data X that `ens` misclassifies, where Y are the true classifications.

Weighted classification error is the sum of weight i times the Boolean value that is 1 when `tree` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1 . With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

CompactClassificationEnsemble.loss

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'classiferror' — Fraction of misclassified data, weighted by w .
- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

To write your own loss function, create a function file of the form

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of `ens.X`.
- K is the number of classes in `ens`, represented in `ens.ClassNames`.
- C is an N -by- K logical matrix, with one `true` per row for the true class. The index for each class is its position in `tree.ClassNames`.
- S is an N -by- K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the score output from `predict`.
- W is a numeric vector with N elements, the observation weights.
- $COST$ is a K -by- K numeric matrix of misclassification costs. The default 'classiferror' gives a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

Examples

Create a compact classification ensemble for the ionosphere data, and find the fraction of training data that the ensemble misclassifies:

```
load ionosphere
ada = fitensemble(X,Y,'AdaBoostM1',100,'tree');
```

```
adb = compact(ada);  
L = loss(adb,X,Y)
```

```
L =  
    0.0085
```

See Also

[loss](#) | [edge](#) | [margin](#) | [predict](#)

CompactClassificationTree.loss

Purpose Classification error

Syntax

```
L = loss(tree,X,Y)
L = loss(tree,X,Y,Name,Value)
L = loss(tree,X,Y,'subtrees',subtreevector)
[L,se] = loss(tree,X,Y,'subtrees',subtreevector)
[L,se,NLeaf] = loss(tree,X,Y,'subtrees',subtreevector)
[L,se,NLeaf,bestlevel] = loss(tree,X,Y,'subtrees',
    subtreevector)
[L,...] =
loss(tree,X,Y,'subtrees',subtreevector,Name,Value)
```

Description

`L = loss(tree,X,Y)` returns a scalar representing how well tree classifies the data in `X`, when `Y` contains the true classifications.

`L = loss(tree,X,Y,Name,Value)` returns the loss with additional options specified by one or more `Name,Value` pair arguments.

`L = loss(tree,X,Y,'subtrees',subtreevector)` returns a vector of classification errors for the trees in the pruning sequence `subtreevector`.

`[L,se] = loss(tree,X,Y,'subtrees',subtreevector)` returns the vector of standard errors of the classification errors.

Note `loss` returns `se` and further outputs only when the `lossfun` name-value pair is the default `'classiferror'`.

`[L,se,NLeaf] = loss(tree,X,Y,'subtrees',subtreevector)` returns the vector of numbers of leaf nodes in the trees of the pruning sequence.

`[L,se,NLeaf,bestlevel] = loss(tree,X,Y,'subtrees',subtreevector)` returns the best pruning level as defined in the `treeSize` name-value pair. By default, `bestlevel` is the pruning level that gives loss within one standard deviation of minimal loss.

```
[L,...] =  
loss(tree,X,Y,'subtrees',subtreevector,Name,Value)  
returns loss statistics with additional options specified by one or  
more Name,Value pair arguments.
```

Input Arguments

tree

A classification tree or compact classification tree constructed by `ClassificationTree.fit` or `compact`.

X

Matrix of data to classify. Each row of `X` represents one observation, and each column represents one predictor. `X` must have the same number of columns as the data used to train `tree`. `X` should have the same number of rows as the number of elements in `Y`.

Y

Classification of `X`. `Y` should be of the same type as the classification used to train `tree`, and its number of elements should equal the number of rows of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

lossfun

Function handle or string representing a loss function. Built-in loss functions:

- 'binodeviance' — See “Loss Functions” on page 20-1221
- 'classiferror' — Fraction of misclassified observations. See “Loss Functions” on page 20-1221.

CompactClassificationTree.loss

- 'exponential' — See “Loss Functions” on page 20-1221
- 'mincost' — Smallest misclassification cost as given by the `tree.Cost` matrix. See “Loss Functions” on page 20-1221.

You can write your own loss function in the syntax described in “Loss Functions” on page 20-1221.

Default: 'mincost'

weights

A numeric vector of length N , where N is the number of rows of `X`. `weights` are nonnegative. When you supply `weights`, `loss` computes weighted classification cost.

Default: `ones(N,1)`

Name, Value arguments associated with pruning subtrees:

subtrees

A vector with integer values from 0 (full unpruned tree) to the maximal pruning level `max(tree.PruneList)`. You can set `subtrees` to 'all', meaning the entire pruning sequence.

Default: 0

treesize

One of the following strings:

- 'se' — `loss` returns the highest pruning level with loss within one standard deviation of the minimum ($L+se$, where L and se relate to the smallest value in `subtrees`).
- 'min' — `loss` returns the element of `subtrees` with smallest loss, usually the smallest element of `subtrees`.

Output Arguments

L

Classification error, a vector the length of subtrees. The meaning of the error depends on the values in `weights` and `lossfun`; see “Classification Error” on page 20-1221.

se

Standard error of loss, a vector the length of subtrees.

NLeaf

Number of leaves (terminal nodes) in the pruned subtrees, a vector the length of subtrees.

bestlevel

A scalar whose value depends on `treesize`:

- `treesize = 'se'` — `loss` returns the highest pruning level with loss within one standard deviation of the minimum ($L+se$, where L and se relate to the smallest value in subtrees).
- `treesize = 'min'` — `loss` returns the element of subtrees with smallest loss, usually the smallest element of subtrees.

Definitions

Classification Error

The default classification error is the fraction of data X that `tree` misclassifies, where Y represents the true classifications.

Weighted classification error is the sum of weight i times the Boolean value that is 1 when `tree` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

- `'binodeviance'` — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

CompactClassificationTree.loss

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

- 'classiferror' — Predict the label with the largest posterior probability. The loss is then the fraction of misclassified observations.
- 'mincost' — Predict the label with the smallest expected misclassification cost, with expectation taken over the posterior probability, and cost as given by the Cost property of the classifier (a matrix). The loss is then the true misclassification cost averaged over the observations.

To write your own loss function, create a function file in this form:

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of X.
- K is the number of classes in the classifier, represented in the ClassNames property.
- C is an N-by-K logical matrix, with one true per row for the true class. The index for each class is its position in the ClassNames property.
- S is an N-by-K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from predict.
- W is a numeric vector with N elements, the observation weights. If you pass W, the elements are normalized to sum to the prior probabilities in the respective classes.
- COST is a K-by-K numeric matrix of misclassification costs. For example, you can use `COST = ones(K) - eye(K)`, which means a cost of 0 for correct classification, and 1 for misclassification.

- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

True Misclassification Cost

There are two costs associated with classification: the true misclassification cost per class, and the expected misclassification cost per observation.

You can set the true misclassification cost per class in the `Cost` name-value pair when you create the classifier using the `ClassificationTree.fit` method. `Cost(i, j)` is the cost of classifying an observation into class `j` if its true class is `i`. By default, `Cost(i, j)=1` if `i~j`, and `Cost(i, j)=0` if `i=j`. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

Expected Misclassification Cost

There are two costs associated with classification: the true misclassification cost per class, and the expected misclassification cost per observation.

Suppose you have `Nobs` observations that you want to classify with a trained classifier. Suppose you have `K` classes. You place the observations into a matrix `Xnew` with one observation per row.

The expected cost matrix `CE` has size `Nobs`-by-`K`. Each row of `CE` contains the expected (average) cost of classifying the observation into each of the `K` classes. `CE(n, k)` is

$$\sum_{i=1}^K \hat{P}(i | X_{new}(n)) C(k | i),$$

where

- `K` is the number of classes.

CompactClassificationTree.loss

- $\hat{P}(i | X_{new}(n))$ is the posterior probability of class i for observation $X_{new}(n)$.
- $C(k | i)$ is the true misclassification cost of classifying an observation as k when its true class is i .

Score (tree)

For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

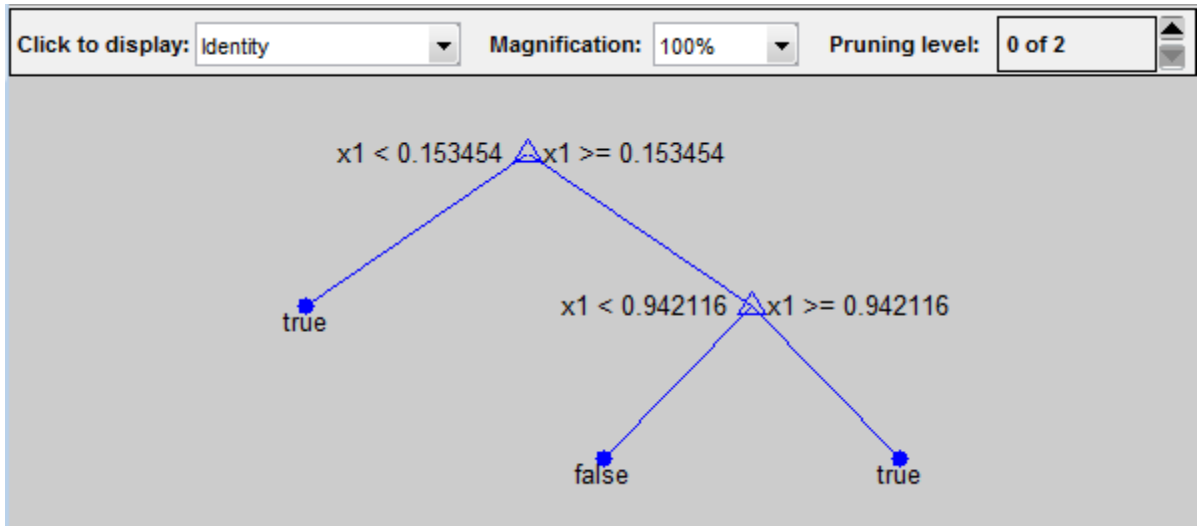
For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```

CompactClassificationTree.loss

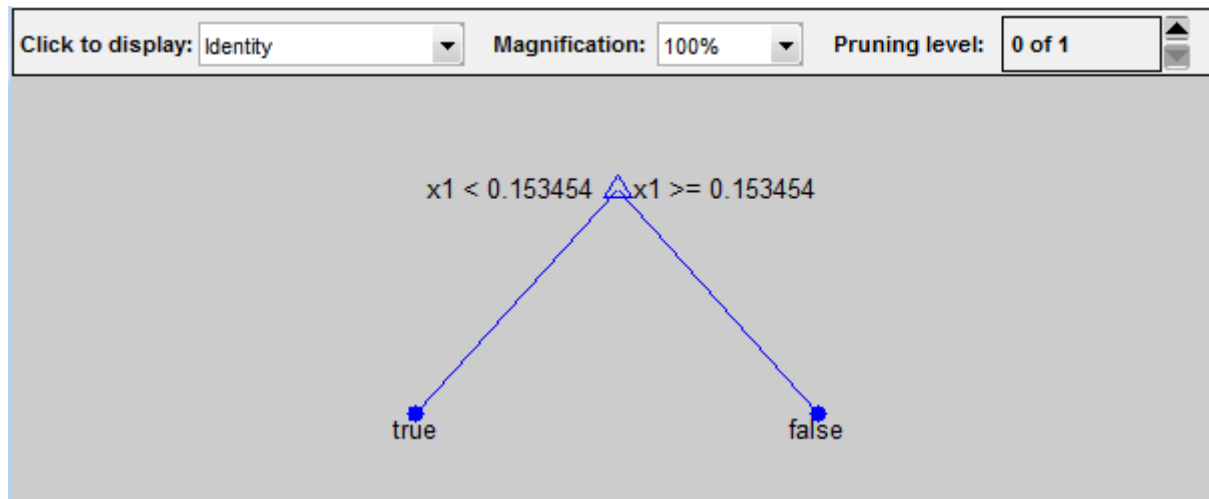


2

Prune the tree:

```
tree1 = prune(tree, 'level', 1);  
view(tree1, 'mode', 'graph')
```

CompactClassificationTree.loss



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
    0.9059    0.0941    0.8147  
    0.9059    0.0941    0.9058  
         0    1.0000    0.1270  
    0.9059    0.0941    0.9134  
    0.9059    0.0941    0.6324  
         0    1.0000    0.0975  
    0.9059    0.0941    0.2785
```

0.9059	0.0941	0.5469
0.9059	0.0941	0.9575
0.9059	0.0941	0.9649

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range $(.95, 1)$ instead of the expected 5 observations.

Examples

Compute the resubstituted classification error for the ionosphere data:

```
load ionosphere
tree = ClassificationTree.fit(X,Y);
L = loss(tree,X,Y)
```

```
L =
    0.0114
```

See Also

[margin](#) | [edge](#) | [predict](#)

CompactRegressionEnsemble.loss

Purpose Regression error

Syntax
`L = loss(ens,X,Y)`
`L = loss(ens,X,Y,Name,Value)`

Description
`L = loss(ens,X,Y)` returns the mean squared error between the predictions of `ens` to the data in `X`, compared to the true responses `Y`.
`L = loss(ens,X,Y,Name,Value)` computes the error in prediction with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A regression ensemble created with `fitensemble`, or the compact method.

X

A matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

NaN values in `X` are taken to be missing values. Observations with all missing values for `X` are not used in the calculation of loss.

Y

A numeric column vector with the same number of rows as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

NaN values in `Y` are taken to be missing values. Observations with missing values for `Y` are not used in the calculation of loss.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

Indices of weak learners in the ensemble ranging from 1 to `ens.NTrained`. `oobEdge` uses only these learners for calculating loss.

Default: `1:NTrained`

lossfun

Function handle for loss function, or the string `'mse'`, meaning mean squared error. If you pass a function handle `fun`, `loss` calls it as

```
fun(Y,Yfit,W)
```

where `Y`, `Yfit`, and `W` are numeric vectors of the same length.

- `Y` is the observed response.
- `Yfit` is the predicted response.
- `W` is the observation weights.

The returned value `fun(Y,Yfit,W)` should be a scalar.

Default: `'mse'`

mode

String representing the meaning of the output `L`:

- `'ensemble'` — `L` is a scalar value, the loss for the entire ensemble.
- `'individual'` — `L` is a vector with one element per trained learner.
- `'cumulative'` — `L` is a vector in which element `J` is obtained by using learners `1:J` from the input list of learners.

CompactRegressionEnsemble.loss

Default: 'ensemble'

UseObsForLearner

A logical matrix of size N-by-NTrained, where N is the number of observations in `ens.X`, and NTrained is the number of weak learners. When `UseObsForLearner(I,J)` is true, `predict` uses learner J in predicting observation I.

Default: `true(N,NTrained)`

weights

Numeric vector of observation weights with the same number of elements as Y. The formula for loss with weights is in “Weighted Mean Squared Error” on page 20-1230.

Default: `ones(size(Y))`

Output Arguments

L

Weighted mean squared error of predictions. The formula for loss is in “Weighted Mean Squared Error” on page 20-1230.

Definitions

Weighted Mean Squared Error

Let n be the number of rows of data, x_j be the j th row of data, y_j be the true response to x_j , and let $f(x_j)$ be the response prediction of `ens` to x_j . Let w be the vector of weights (all one by default).

First the weights are divided by their sum so they add to one: $w \rightarrow w/\sum w$. The mean squared error L is

$$L = \sum_{j=1}^n w_j (f(x_j) - y_j)^2.$$

Examples

Find the loss of an ensemble predictor of the `carsmall` data to find MPG as a function of engine displacement, horsepower, and vehicle weight:


```
load carsmall
X = [Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'LSBoost',100,'Tree');
L = loss(ens,X,MPG)
```

```
L =
    4.3904
```

See Also

[predict](#) | [fitensemble](#)

CompactRegressionTree.loss

Purpose Regression error

Syntax

```
L = loss(tree,X,Y)
[L,se] = loss(tree,X,Y)
[L,se,NLeaf] = loss(tree,X,Y)
[L,se,NLeaf,bestlevel] = loss(tree,X,Y)
L = loss(tree,X,Y,Name,Value)
```

Description

`L = loss(tree,X,Y)` returns the mean squared error between the predictions of `tree` to the data in `X`, compared to the true responses `Y`.

`[L,se] = loss(tree,X,Y)` returns the standard error of the loss.

`[L,se,NLeaf] = loss(tree,X,Y)` returns the number of leaves (terminal nodes) in the tree.

`[L,se,NLeaf,bestlevel] = loss(tree,X,Y)` returns the optimal pruning level for `tree`.

`L = loss(tree,X,Y,Name,Value)` computes the error in prediction with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

tree

Regression tree created with `RegressionTree.fit`, or the `compact` method.

X

A matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

Y

A numeric column vector with the same number of rows as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding

value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

lossfun

Function handle for loss, or the string 'mse' representing mean-squared error. If you pass a function handle fun, loss calls fun as:

```
fun(Y,Yfit,W)
```

- Y is the vector of true responses.
- Yfit is the vector of predicted responses.
- W is the observation weights. If you pass W, the elements are normalized to sum to 1.

All the vectors have the same number of rows as Y.

Default: 'mse'

subtrees

A vector with integer values from 0 (full unpruned tree) to the maximal pruning level `max(tree.PruneList)`. You can set subtrees to 'all', meaning the entire pruning sequence.

Default: 0

treesize

A string, either:

- 'se' — loss returns `bestlevel` that corresponds to the smallest tree whose mean squared error (MSE) is within one standard error of the minimum MSE.

CompactRegressionTree.loss

- 'min' — loss returns `bestlevel` that corresponds to the minimal MSE tree.

weights

Numeric vector of observation weights with the same number of elements as `Y`.

Default: `ones(size(Y))`

Output Arguments

L

Classification error, a vector the length of `subtrees`. The error for each tree is the mean squared error, weighted with `weights`. If you include `lossfun`, L reflects the loss calculated with `lossfun`.

se

Standard error of loss, a vector the length of `subtrees`.

Nleaf

Number of leaves (terminal nodes) in the pruned subtrees, a vector the length of `subtrees`.

bestlevel

A scalar whose value depends on `treesize`:

- `treesize = 'se'` — loss returns the highest pruning level with loss within one standard deviation of the minimum (`L+se`, where `L` and `se` relate to the smallest value in `subtrees`).
- `treesize = 'min'` — loss returns the element of `subtrees` with smallest loss, usually the smallest element of `subtrees`.

Definitions

Mean Squared Error

The mean squared error m of the predictions $f(X_n)$ with weight vector w is

$$m = \frac{\sum w_n (f(X_n) - Y_n)^2}{\sum w_n}.$$

Examples

Find the loss of a regression tree predictor of the carsmall data to find MPG as a function of engine displacement, horsepower, and vehicle weight:

```
load carsmall
X = [Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
L = loss(tree,X,MPG)
```

```
L =
    4.8952
```

Find the pruning level that gives the optimal level of loss for the carsmall data:

```
load carsmall
X = [Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
[L,se,NLeaf,bestlevel] = loss(tree,X,MPG,'Subtrees','all');
bestlevel
```

```
bestlevel =
    4
```

See Also

predict

paretotails.lowerparams

Purpose Lower Pareto tails parameters

Syntax `params = lowerparams(obj)`

Description `params = lowerparams(obj)` returns the 2-element vector `params` of shape and scale parameters, respectively, of the lower tail of the Pareto tails object `obj`. `lowerparams` does not return a location parameter.

Examples Fit Pareto tails to a *t* distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);  
obj = paretotails(t,0.1,0.9);
```

```
lowerparams(obj)  
ans =  
    -0.1901    1.1898  
upperparams(obj)  
ans =  
    0.3646    0.5103
```

See Also `paretotails` | `upperparams`

Purpose Less than relation for handles

Syntax `h1 < h2`

Description `h1 < h2` performs element-wise comparisons between handle arrays `h1` and `h2`. `h1` and `h2` must be of the same dimensions unless one is a scalar. The result is a logical array of the same dimensions, where each element is an element-wise `<` result.

If one of `h1` or `h2` is scalar, scalar expansion is performed and the result will match the dimensions of the array that is not scalar.

`tf = lt(h1, h2)` stores the result in a logical array of the same dimensions.

See Also `grandstream | eq | ge | gt | le | ne`

lsline

Purpose Add least-squares line to scatter plot

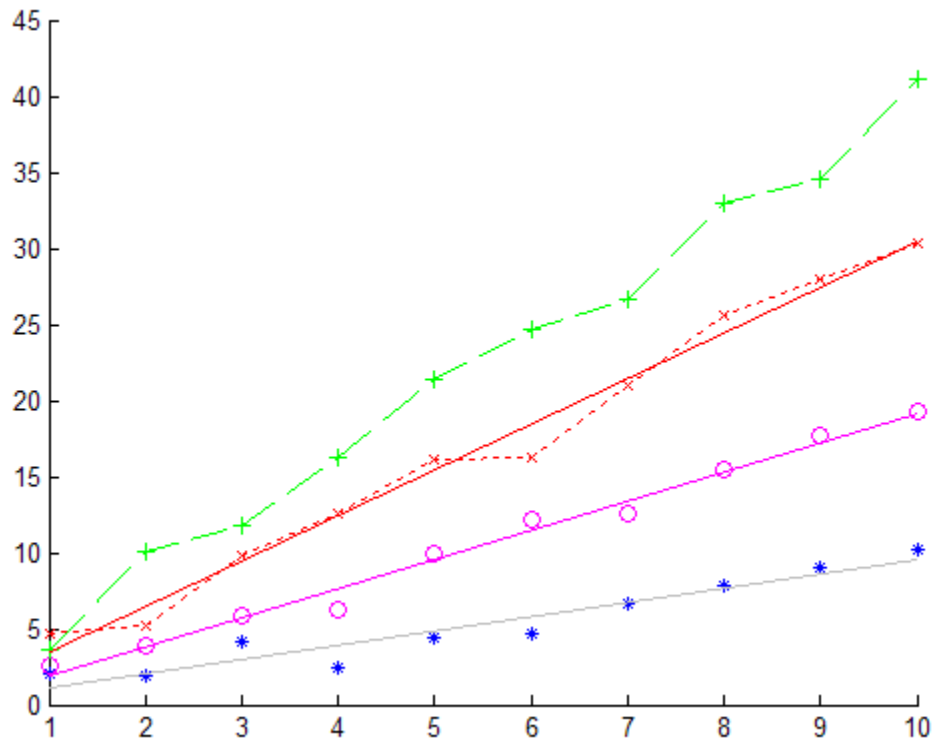
Syntax `lsline`
`h = lsline`

Description `lsline` superimposes a least-squares line on each scatter plot in the current axes. Scatter plots are produced by the MATLAB `scatter` and `plot` functions. Data points connected with solid, dashed, or dash-dot lines ('-', '--', or '-.') are not considered to be scatter plots by `lsline`, and are ignored.

`h = lsline` returns a column vector of handles `h` to the least-squares lines.

Examples Use `lsline` together with scatter plots produced by `scatter` and various line styles of `plot`:

```
x = 1:10;  
  
y1 = x + randn(1,10);  
scatter(x,y1,25,'b','*')  
hold on  
  
y2 = 2*x + randn(1,10);  
plot(x,y2,'mo')  
  
y3 = 3*x + randn(1,10);  
plot(x,y3,'rx:')  
  
y4 = 4*x + randn(1,10);  
plot(x,y4,'g+--')  
  
lsline
```


**See Also**

scatter | plot | refline | refcurve | gline

mad

Purpose Mean or median absolute deviation

Syntax

```
y = mad(X)
Y = mad(X,1)
Y = mad(X,0)
```

Description `y = mad(X)` returns the mean absolute deviation of the values in `X`. For vector input, `y` is `mean(abs(X-mean(X)))`. For a matrix input, `y` is a row vector containing the mean absolute deviation of each column of `X`. For N -dimensional arrays, `mad` operates along the first nonsingleton dimension of `X`.

`Y = mad(X,1)` returns the median absolute deviation of the values in `X`. For vector input, `y` is `median(abs(X-median(X)))`. For a matrix input, `y` is a row vector containing the median absolute deviation of each column of `X`. For N -dimensional arrays, `mad` operates along the first nonsingleton dimension of `X`.

`Y = mad(X,0)` is the same as `mad(X)`, and returns the mean absolute deviation of the values in `X`.

`mad(X,flag,dim)` computes absolute deviations along the dimension `dim` of `X`. `flag` is 0 or 1 to indicate mean or median absolute deviation, respectively.

`mad` treats NaNs as missing values and removes them.

For normally distributed data, multiply `mad` by one of the following factors to obtain an estimate of the normal scale parameter σ :

- `sigma = 1.253*mad(X,0)` — For mean absolute deviation
- `sigma = 1.4826*mad(X,1)` — For median absolute deviation

Examples The following compares the robustness of different scale estimates for normally distributed data in the presence of outliers:

```
x = normrnd(0,1,1,50);
xo = [x 10]; % Add outlier
```

```
r1 = std(xo)/std(x)
r1 =
    1.7385
```

```
r2 = mad(xo,0)/mad(x,0)
r2 =
    1.2306
```

```
r3 = mad(xo,1)/mad(x,1)
r3 =
    1.0602
```

References

- [1] Mosteller, F., and J. Tukey. *Data Analysis and Regression*. Upper Saddle River, NJ: Addison-Wesley, 1977.
- [2] Sachs, L. *Applied Statistics: A Handbook of Techniques*. New York: Springer-Verlag, 1984, p. 253.

See Also

std | range | iqr

mahal

Purpose Mahalanobis distance

Syntax `d = mahal(Y,X)`

Description `d = mahal(Y,X)` computes the Mahalanobis distance (in squared units) of each observation in `Y` from the reference sample in matrix `X`. If `Y` is n -by- m , where n is the number of observations and m is the dimension of the data, `d` is n -by-1. `X` and `Y` must have the same number of columns, but can have different numbers of rows. `X` must have more rows than columns.

For observation `I`, the Mahalanobis distance is defined by $d(I) = (Y(I,:) - \mu) * \text{inv}(\text{SIGMA}) * (Y(I,:) - \mu)'$, where `mu` and `SIGMA` are the sample mean and covariance of the data in `X`. `mahal` performs an equivalent, but more efficient, computation.

Examples Generate some correlated bivariate data in `X` and compare the Mahalanobis and squared Euclidean distances of observations in `Y`:

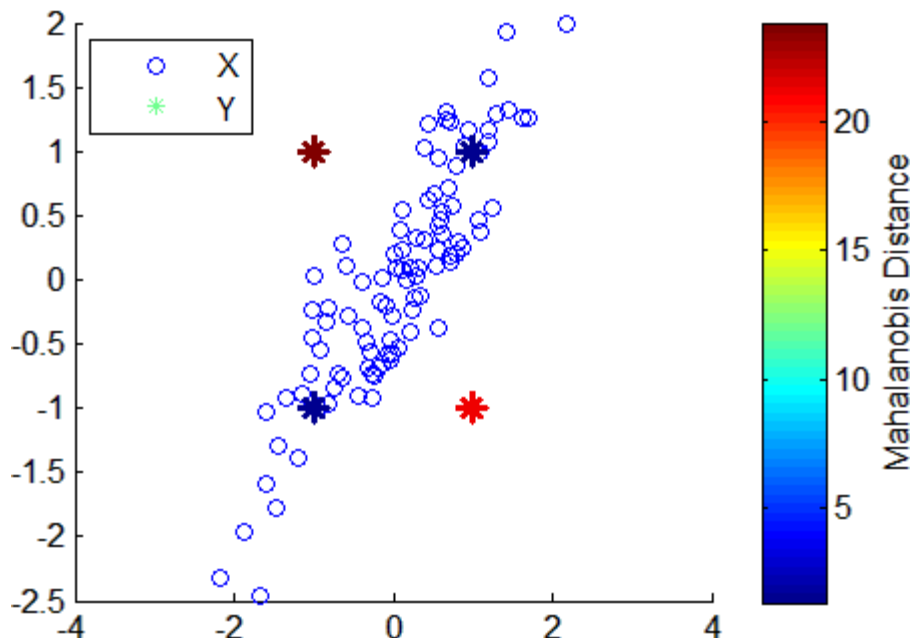
```
X = mvnrnd([0;0],[1 .9;.9 1],100);
Y = [1 1;1 -1;-1 1;-1 -1];

d1 = mahal(Y,X) % Mahalanobis
d1 =
    1.3592
   21.1013
   23.8086
    1.4727

d2 = sum((Y-repmat(mean(X),4,1)).^2, 2) % Squared Euclidean
d2 =
    1.9310
    1.8821
    2.1228
    2.0739

scatter(X(:,1),X(:,2))
```

```
hold on
scatter(Y(:,1),Y(:,2),100,d1,'*', 'LineWidth',2)
hb = colorbar;
ylabel(hb,'Mahalanobis Distance')
legend('X','Y','Location','NW')
```



The observations in Y with equal coordinate values are much closer to X in Mahalanobis distance than observations with opposite coordinate values, even though all observations are approximately equidistant from the mean of X in Euclidean distance. The Mahalanobis distance, by considering the covariance of the data and the scales of the different variables, is useful for detecting outliers in such cases.

See Also

`pdist` | `mahal`

CompactClassificationDiscriminant.mahal

Purpose Mahalanobis distance to class means

Syntax
M = mahal(obj,X)
M = mahal(obj,X,Name,Value)

Description M = mahal(obj,X) returns the squared Mahalanobis distances from observations in X to the class means in obj.
M = mahal(obj,X,Name,Value) computes the squared Mahalanobis distance with additional options specified by one or more Name,Value pair arguments.

Input Arguments

obj
Discriminant analysis classifier of class ClassificationDiscriminant or CompactClassificationDiscriminant, typically constructed with ClassificationDiscriminant.fit.

X
Numeric matrix of size n-by-p, where p is the number of predictors in obj, and n is any positive integer. mahal computes the Mahalanobis distances from the rows of X to each of the K means of the classes in obj.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.

ClassLabels

Class labels consisting of n elements of obj.Y, where n is the number of rows of X.

Output Arguments

M

Size and meaning of output M depends on whether the `ClassLabels` name-value pair is present:

- No `ClassLabels` — M is a numeric matrix of size n-by-K, where K is the number of classes in `obj`, and n is the number of rows in X. $M(i, j)$ is the squared Mahalanobis distance from the *i*th row of X to the mean of class *j*.
- `ClassLabels` exists — M is a column vector with n elements. $M(i)$ is the squared Mahalanobis distance from the *i*th row of X to the mean for the class of the *i*th element of `ClassLabels`.

Definitions

Mahalanobis Distance

The Mahalanobis distance $d(x,y)$ between *n*-dimensional points *x* and *y*, with respect to a given *n*-by-*n* covariance matrix *S*, is

$$d(x,y) = \sqrt{(x-y)^T S^{-1} (x-y)}.$$

Examples

Find the Mahalanobis distances from the mean of the Fisher iris data to the class means, using distinct covariance matrices for each class:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species,...
    'DiscrimType','quadratic');
mahadist = mahal(obj,mean(meas))

mahadist =
    220.0667    5.0254    30.5804
```

See Also

`CompactClassificationDiscriminant` | `mahal` | `gmdistribution`

How To

- “Discriminant Analysis” on page 12-3

gmdistribution.mahal

Purpose Mahalanobis distance to component means

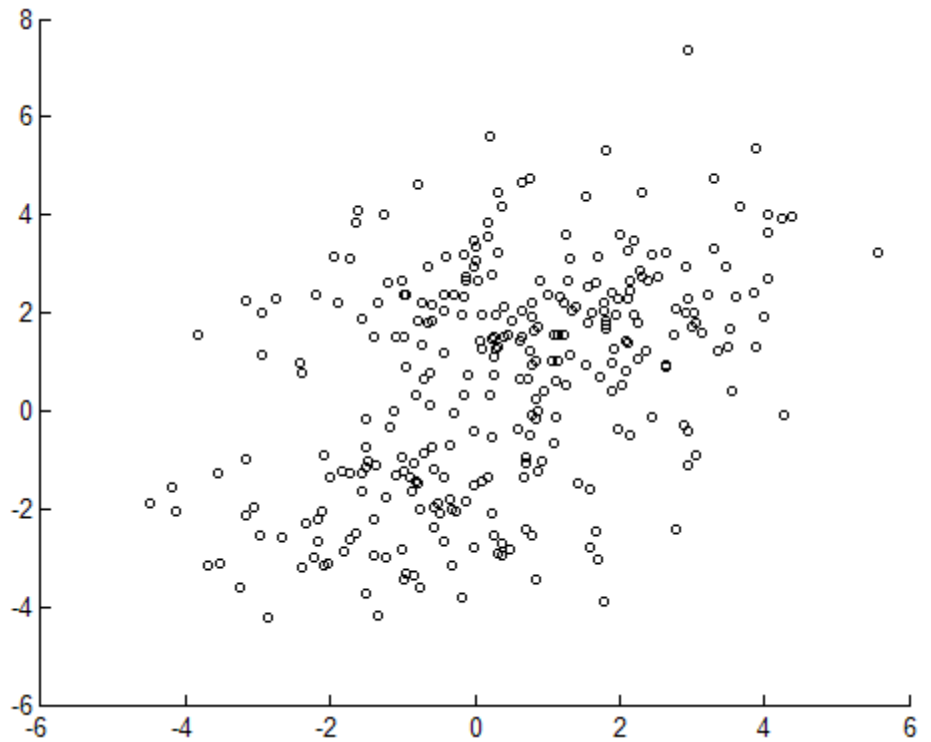
Syntax `D = mahal(obj,X)`

Description `D = mahal(obj,X)` computes the Mahalanobis distance (in squared units) of each observation in `X` to the mean of each of the k components of the Gaussian mixture distribution defined by `obj`. `obj` is an object created by `gmdistribution` or `fit`. `X` is an n -by- d matrix, where n is the number of observations and d is the dimension of the data. `D` is n -by- k , with `D(I,J)` the distance of observation `I` from the mean of component `J`.

Examples Generate data from a mixture of two bivariate Gaussian distributions using the `mvnrnd` function:

```
MU1 = [1 2];
SIGMA1 = [2 0; 0 .5];
MU2 = [-3 -5];
SIGMA2 = [1 0; 0 1];
X = [mvnrnd(MU1,SIGMA1,1000);mvnrnd(MU2,SIGMA2,1000)];

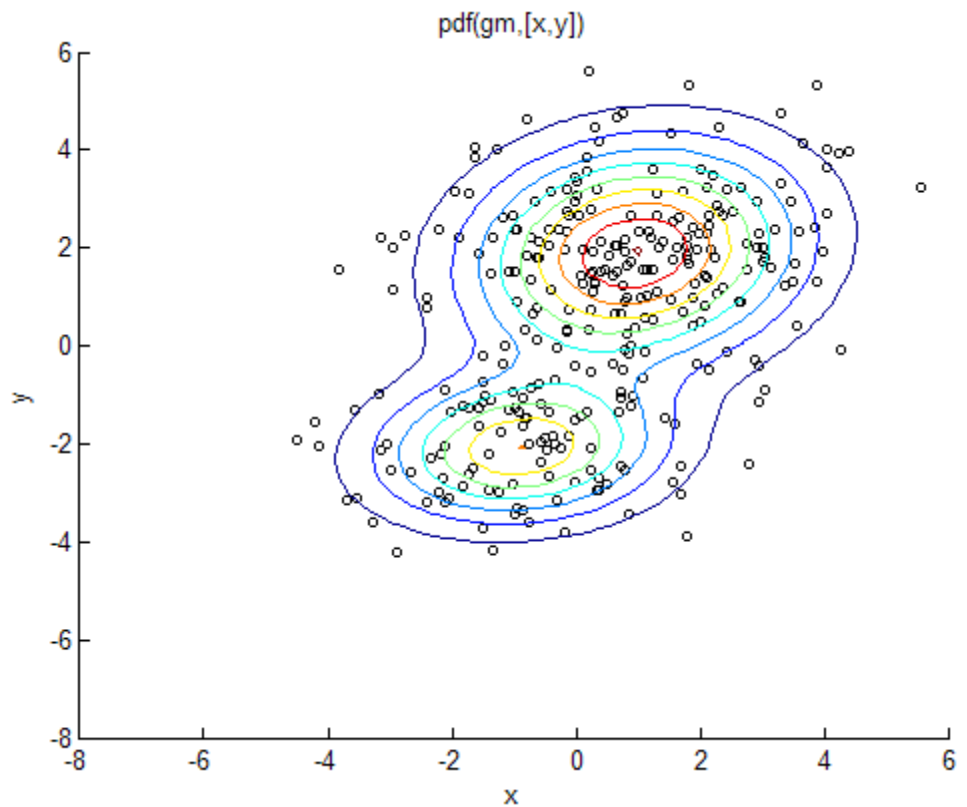
scatter(X(:,1),X(:,2),10,'.')
hold on
```

Fit a two-component Gaussian mixture model:

```
obj = gmdistribution.fit(X,2);  
h = ezcontour(@(x,y)pdf(obj,[x y]),[-8 6],[-8 6]);
```

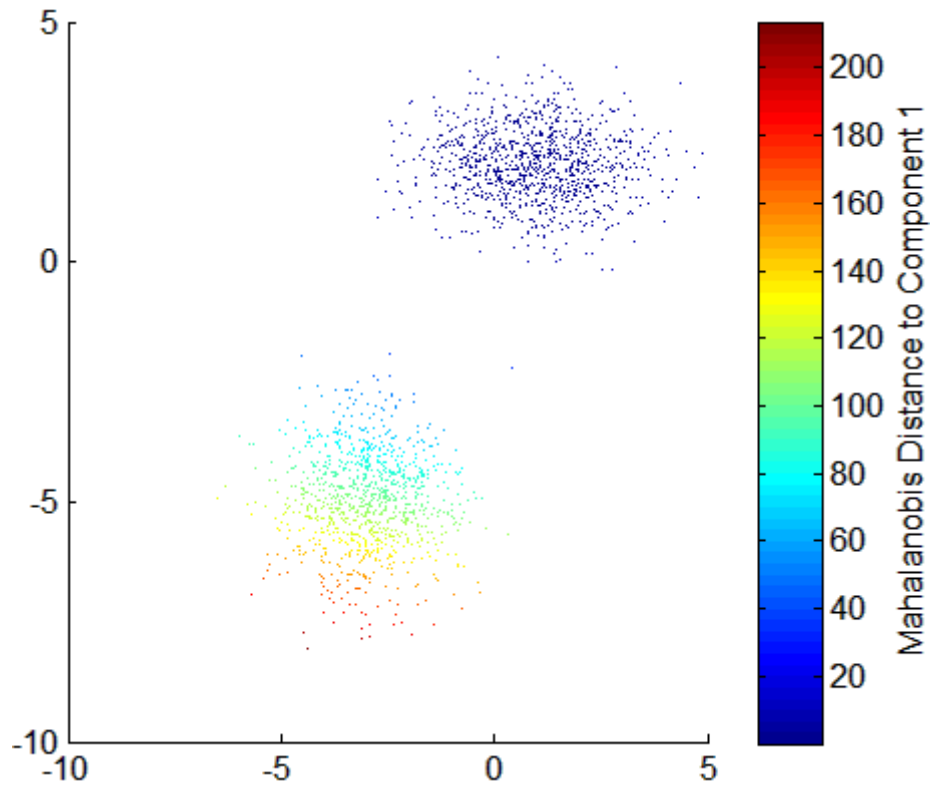
gmdistribution.mahal



Compute the Mahalanobis distance of each point in X to the mean of each component of obj:

```
D = mahal(obj,X);
```

```
delete(h)  
scatter(X(:,1),X(:,2),10,D(:,1),'.')  
hb = colorbar;  
ylabel(hb,'Mahalanobis Distance to Component 1')
```



See Also

[gmdistribution](#) | [cluster](#) | [posterior](#) | [mahal](#)

maineffectsplot

Purpose Main effects plot for grouped data

Syntax `maineffectsplot(Y,GROUP)`
`maineffectsplot(Y,GROUP,param1,val1,param2,val2,...)`
`[figh,AXESH] = maineffectsplot(...)`

Description `maineffectsplot(Y,GROUP)` displays main effects plots for the group means of matrix `Y` with groups defined by entries in the cell array `GROUP`. `Y` is a numeric matrix or vector. If `Y` is a matrix, the rows represent different observations and the columns represent replications of each observation. Each cell of `GROUP` must contain a grouping variable that can be a categorical variable, numeric vector, character matrix, or single-column cell array of strings. `GROUP` can also be a matrix whose columns represent different grouping variables. Each grouping variable must have the same number of rows as `Y`. The number of grouping variables must be greater than 1.

The display has one subplot per grouping variable, with each subplot showing the group means of `Y` as a function of one grouping variable.

`maineffectsplot(Y,GROUP,param1,val1,param2,val2,...)` specifies one or more of the following name/value pairs:

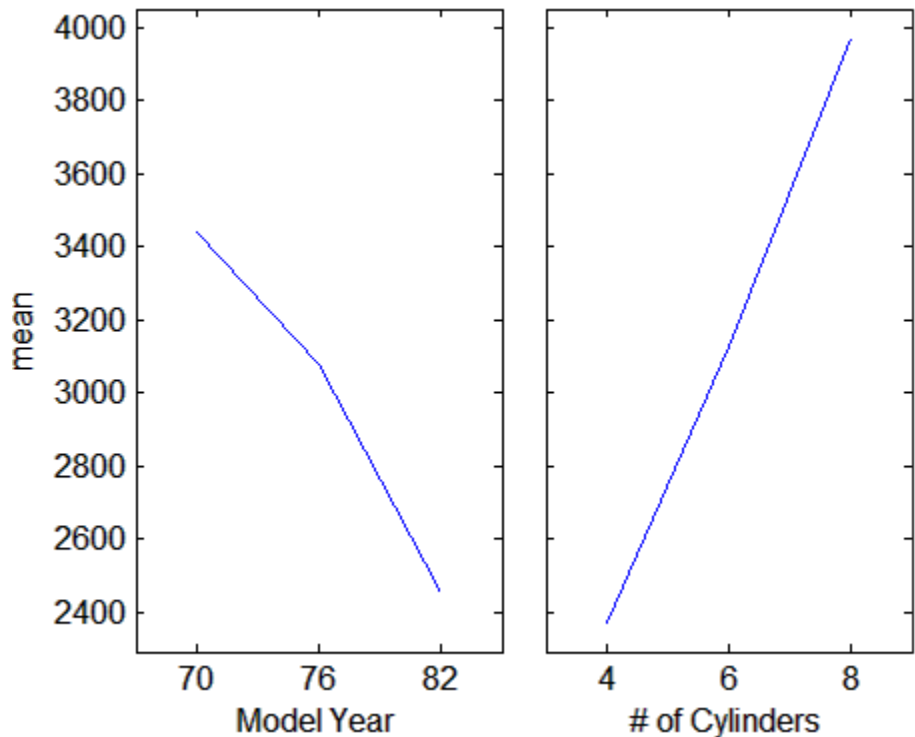
- `'varnames'` — Grouping variable names in a character matrix or a cell array of strings, one per grouping variable. Default names are `'X1'`, `'X2'`,
- `'statistic'` — String values that indicate whether the group mean or the group standard deviation should be plotted. Use `'mean'` or `'std'`. The default is `'mean'`. If the value is `'std'`, `Y` is required to have multiple columns.
- `'parent'` — A handle to the figure window for the plots. The default is the current figure window.

`[figh,AXESH] = maineffectsplot(...)` returns the handle `figh` to the figure window and an array of handles `AXESH` to the subplot axes.

Examples

Display main effects plots for car weight with two grouping variables, model year and number of cylinders:

```
load carsmall;  
maineffectsplot(Weight,{Model_Year,Cylinders}, ...  
               'varnames',{'Model Year','# of Cylinders'})
```



See Also

[interactionplot](#) | [multivarichart](#)

How To

- “Grouping Variables” on page 2-72

ClassificationDiscriminant.make

Purpose Construct discriminant analysis classifier from parameters

Syntax
`cobj = ClassificationDiscriminant.make(Mu, Sigma)`
`cobj = ClassificationDiscriminant.make(Mu, Sigma, Name, Value)`

Description `cobj = ClassificationDiscriminant.make(Mu, Sigma)` constructs a compact discriminant analysis classifier from the class means `Mu` and covariance matrix `Sigma`.

`cobj = ClassificationDiscriminant.make(Mu, Sigma, Name, Value)` constructs a compact classifier with additional options specified by one or more `Name, Value` pair arguments.

Tips

- You can change the discriminant type using dot addressing after constructing `cobj`:

```
cobj.DiscrimType = 'discrimType'
```

where *discrimType* is one of 'linear', 'quadratic', 'diagLinear', 'diagQuadratic', 'pseudoLinear', or 'pseudoQuadratic'. You can change between linear types or between quadratic types, but cannot change between a linear and a quadratic type.

- `cobj` is a linear classifier when `Sigma` is a matrix. `cobj` is a quadratic classifier when `Sigma` is a three-dimensional array.

Input Arguments

Mu

Matrix of class means of size K-by-p, where K is the number of classes, and p is the number of predictors. Each row of `Mu` represents the mean of the multivariate normal distribution of the corresponding class. The class indices are in the `ClassNames` attribute.

Sigma

Within-class covariance matrix or matrices.

- For a linear discriminant, `Sigma` is a symmetric, positive semidefinite matrix of size p -by- p , where p is the number of predictors.
- For a quadratic discriminant, `Sigma` is an array of size p -by- p -by- K , where K is the number of classes. For each i , `Sigma(:, :, i)` is a symmetric, positive semidefinite matrix.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

ClassNames

Array of class names. Use any data type for a grouping variable: a numeric vector, vector of categorical variables (nominal or ordinal), logical vector, character array, or cell array of strings.

`ClassNames` names the classes, as ordered in `Mu`.

Default: $1:K$, where K is the number of classes (the number of rows of `Mu`)

Cost

Square matrix, where `Cost(i, j)` is the cost of classifying a point into class j if its true class is i . Alternatively, `Cost` can be a structure `S` having two fields: `S.ClassNames` containing the group names as a variable of the same type as `Y`, and `S.ClassificationCosts` containing the cost matrix.

Default: `Cost(i, j) = 1` if $i \neq j$, and `Cost(i, j) = 0` if $i = j$

PredictorNames

ClassificationDiscriminant.make

Cell array of names for the predictor variables, in the order in which they appear in X.

Default: {'x1', 'x2', ...}

prior

Prior probabilities for each class. Specify as one of:

- 'uniform', a string meaning all class prior probabilities are equal
- A vector (one scalar value for each class)
- A structure S with two fields:
 - S.ClassNames containing the class names as a variable of the same type as ClassNames
 - S.ClassProbs containing a vector of corresponding probabilities

Default: 'uniform'

ResponseName

Name of the response variable Y, a string.

Default: 'Y'

Output Arguments

cobj

Discriminant analysis classifier, of class CompactClassificationDiscriminant.

Examples

Construct a compact linear discriminant analysis classifier from the means and covariances of the Fisher iris data:

```
load fisheriris
mu(1,:) = mean(meas(1:50,:));
```



```
mu(2,:) = mean(meas(51:100,:));
mu(3,:) = mean(meas(101:150,:));

mm1 = repmat(mu(1,:),50,1);
mm2 = repmat(mu(2,:),50,1);
mm3 = repmat(mu(3,:),50,1);
cc = meas;
cc(1:50,:) = cc(1:50,:) - mm1;
cc(51:100,:) = cc(51:100,:) - mm2;
cc(101:150,:) = cc(101:150,:) - mm3;
sigstar = cc' * cc / 147; % unbiased estimator of sigma
cpct = ClassificationDiscriminant.make(mu,sigstar,...
    'ClassNames',{'setosa','versicolor','virginica'})

cpct =
classreg.learning.classif.CompactClassificationDiscriminant:
  PredictorNames: {'x1' 'x2' 'x3' 'x4'}
  ResponseName: 'Y'
  ClassNames: {'setosa' 'versicolor' 'virginica'}
  ScoreTransform: 'none'
  DiscrimType: 'linear'
  Mu: [3x4 double]
  Coeffs: [3x3 struct]
```

See Also

[ClassificationDiscriminant.fit](#) | [compact](#) | [CompactClassificationDiscriminant](#)

How To

- “Discriminant Analysis” on page 12-3

manova1

Purpose One-way multivariate analysis of variance

Syntax

```
d = manova1(X,group)
d = manova1(X,group,alpha)
[d,p] = manova1(...)
[d,p,stats] = manova1(...)
```

Description `d = manova1(X,group)` performs a one-way Multivariate Analysis of Variance (MANOVA) for comparing the multivariate means of the columns of `X`, grouped by `group`. `X` is an m -by- n matrix of data values, and each row is a vector of measurements on n variables for a single observation. `group` is a grouping variable defined as a categorical variable, vector, string array, or cell array of strings. Two observations are in the same group if they have the same value in the `group` array. The observations in each group represent a sample from a population.

The function returns `d`, an estimate of the dimension of the space containing the group means. `manova1` tests the null hypothesis that the means of each group are the same n -dimensional multivariate vector, and that any difference observed in the sample `X` is due to random chance. If `d = 0`, there is no evidence to reject that hypothesis. If `d = 1`, then you can reject the null hypothesis at the 5% level, but you cannot reject the hypothesis that the multivariate means lie on the same line. Similarly, if `d = 2` the multivariate means may lie on the same plane in n -dimensional space, but not on the same line.

`d = manova1(X,group,alpha)` gives control of the significance level, `alpha`. The return value `d` will be the smallest dimension having $p > \alpha$, where p is a p -value for testing whether the means lie in a space of that dimension.

`[d,p] = manova1(...)` also returns a `p`, a vector of p -values for testing whether the means lie in a space of dimension 0, 1, and so on. The largest possible dimension is either the dimension of the space, or one less than the number of groups. There is one element of `p` for each dimension up to, but not including, the largest.

If the i th p -value is near zero, this casts doubt on the hypothesis that the group means lie on a space of $i-1$ dimensions. The choice of a

critical p -value to determine whether the result is judged statistically significant is left to the researcher and is specified by the value of the input argument `alpha`. It is common to declare a result significant if the p -value is less than 0.05 or 0.01.

`[d,p,stats] = manova1(...)` also returns `stats`, a structure containing additional MANOVA results. The structure contains the following fields.

Field	Contents
W	Within-groups sum of squares and cross-products matrix
B	Between-groups sum of squares and cross-products matrix
T	Total sum of squares and cross-products matrix
dfW	Degrees of freedom for W
dfB	Degrees of freedom for B
dfT	Degrees of freedom for T
lambda	Vector of values of Wilk's lambda test statistic for testing whether the means have dimension 0, 1, etc.
chisq	Transformation of lambda to an approximate chi-square distribution
chisqdf	Degrees of freedom for chisq
eigenval	Eigenvalues of $W^{-1}B$
eigenvec	Eigenvectors of $W^{-1}B$; these are the coefficients for the canonical variables C, and they are scaled so the within-group variance of the canonical variables is 1
canon	Canonical variables C, equal to $XC * \text{eigenvec}$, where XC is X with columns centered by subtracting their means

manova1

Field	Contents
mdist	A vector of Mahalanobis distances from each point to the mean of its group
gmdist	A matrix of Mahalanobis distances between each pair of group means

The canonical variables C are linear combinations of the original variables, chosen to maximize the separation between groups. Specifically, $C(:, 1)$ is the linear combination of the X columns that has the maximum separation between groups. This means that among all possible linear combinations, it is the one with the most significant F statistic in a one-way analysis of variance. $C(:, 2)$ has the maximum separation subject to it being orthogonal to $C(:, 1)$, and so on.

You may find it useful to use the outputs from `manova1` along with other functions to supplement your analysis. For example, you may want to start with a grouped scatter plot matrix of the original variables using `gplotmatrix`. You can use `gscatter` to visualize the group separation using the first two canonical variables. You can use `manovacluster` to graph a dendrogram showing the clusters among the group means.

Assumptions

The MANOVA test makes the following assumptions about the data in X :

- The populations for each group are normally distributed.
- The variance-covariance matrix is the same for each population.
- All observations are mutually independent.

Examples

you can use `manova1` to determine whether there are differences in the averages of four car characteristics, among groups defined by the country where the cars were made.

```
load carbig
[d,p] = manova1([MPG Acceleration Weight Displacement],...
```

```
                                Origin)
d =
  3
p =
  0
  0.0000
  0.0075
  0.1934
```

There are four dimensions in the input matrix, so the group means must lie in a four-dimensional space. `manova1` shows that you cannot reject the hypothesis that the means lie in a 3-D subspace.

References

[1] Krzanowski, W. J. *Principles of Multivariate Analysis: A User's Perspective*. New York: Oxford University Press, 1988.

See Also

`anova1` | `canoncorr` | `gscatter` | `gplotmatrix` | `manovacluster`

How To

- “Grouping Variables” on page 2-72

manovacluster

Purpose Dendrogram of group mean clusters following MANOVA

Syntax
`manovacluster(stats)`
`manovacluster(stats,method)`
`H = manovacluster(stats,method)`

Description `manovacluster(stats)` generates a dendrogram plot of the group means after a multivariate analysis of variance (MANOVA). `stats` is the output `stats` structure from `manova1`. The clusters are computed by applying the single linkage method to the matrix of Mahalanobis distances between group means.

See `dendrogram` for more information on the graphical output from this function. The dendrogram is most useful when the number of groups is large.

`manovacluster(stats,method)` uses the specified method in place of single linkage. `method` can be any of the following character strings that identify ways to create the cluster hierarchy. (See `linkage` for additional information.)

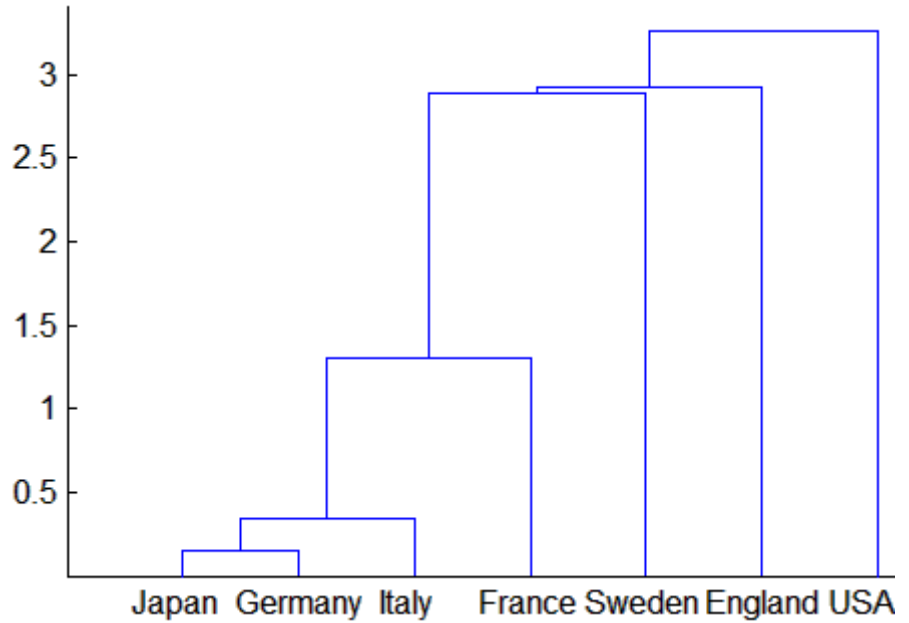
Method	Description
'single'	Shortest distance (default)
'complete'	Largest distance
'average'	Average distance
'centroid'	Centroid distance
'ward'	Incremental sum of squares

`H = manovacluster(stats,method)` returns a vector of handles to the lines in the figure.

Examples Let's analyze the larger car data set to determine which countries produce cars with the most similar characteristics.

```
load carbig
```

```
X = [MPG Acceleration Weight Displacement];  
[d,p,stats] = manova1(X,Origin);  
manovacluster(stats)
```



See Also

[cluster](#) | [dendrogram](#) | [linkage](#) | [manova1](#)

ClassificationKNN.margin

Purpose	Margin of k -nearest neighbor classifier
Syntax	<code>m = margin mdl,X,Y</code>
Description	<code>m = margin mdl,X,Y</code> returns the classification margins for the matrix of predictors X and class labels Y . For the definition, see “Margin” on page 20-1262.
Input Arguments	mdl k -nearest neighbor classifier, created by <code>ClassificationKNN.fit</code> . X Matrix of predictor values. Each column of X represents one variable, and each row represents one observation. Y Grouping variables of response values with the same number of elements (rows) as X . Each entry in Y is the response to the data in the corresponding row of X .
Output Arguments	m Numeric column vector of length <code>size(X,1)</code> . Each entry in m represents the margin for the corresponding rows of X and (true class) Y , computed using <code>mdl</code> .
Definitions	Margin The classification <i>margin</i> is the difference between the classification <i>score</i> for the true class and maximal classification score for the false classes. Score The <i>score</i> of a classification is the posterior probability of the classification. The posterior probability is the number of neighbors that have that classification, divided by the number of neighbors. For a more

detailed definition that includes weights and prior probabilities, see “Posterior Probability” on page 20-1830.

Examples

Margin Calculation

Construct a k -nearest neighbor classifier for the Fisher iris data, where $k = 5$.

Load the data.

```
load fisheriris
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(meas,species,'NumNeighbors',5);
```

Examine the margin of the classifier for a mean observation classified 'versicolor'.

```
X = mean(meas);  
Y = {'versicolor'};  
m = margin(mdl,X,Y)
```

```
m =
```

```
1
```

The classifier has no doubt that 'versicolor' is the correct classification (all five nearest neighbors classify as 'versicolor').

See Also

[ClassificationKNN](#) | [edge](#) | [loss](#) |

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

CompactClassificationDiscriminant.margin

Purpose	Classification margins
Syntax	<code>m = margin(obj,X,Y)</code>
Description	<code>m = margin(obj,X,Y)</code> returns the classification margins for the matrix of predictors <code>X</code> and class labels <code>Y</code> . For the definition, see “Definitions” on page 20-1264.
Input Arguments	<p>obj</p> <p>Discriminant analysis classifier of class <code>ClassificationDiscriminant</code> or <code>CompactClassificationDiscriminant</code>, typically constructed with <code>ClassificationDiscriminant.fit</code>.</p> <p>X</p> <p>Matrix where each row represents an observation, and each column represents a predictor. The number of columns in <code>X</code> must equal the number of predictors in <code>obj</code>.</p> <p>Y</p> <p>Class labels, with the same data type as exists in <code>obj</code>. The number of elements of <code>Y</code> must equal the number of rows of <code>X</code>.</p>
Output Arguments	<p>m</p> <p>Numeric column vector of length <code>size(X,1)</code>. Each entry in <code>m</code> represents the margin for the corresponding rows of <code>X</code> and (true class) <code>Y</code>, computed using <code>obj</code>.</p>
Definitions	<p>Margin</p> <p>The classification <i>margin</i> is the difference between the classification <i>score</i> for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix <code>X</code>. A high value of margin indicates a more reliable prediction than a low value.</p>

Score (discriminant analysis)

For discriminant analysis, the *score* of a classification is the posterior probability of the classification. For the definition of posterior probability in discriminant analysis, see “Posterior Probability” on page 12-7.

Examples

Compute the classification margin for the Fisher iris data, trained on its first two columns of data, and view the last 10 entries:

```
load fisheriris
X = meas(:,1:2);
obj = ClassificationDiscriminant.fit(X,species);
M = margin(obj,X,species);
M(end-10:end)
```

```
ans =
    0.6551
    0.4838
    0.6551
   -0.5127
    0.5659
    0.4611
    0.4949
    0.1024
    0.2787
   -0.1439
   -0.4444
```

The classifier trained on all the data is better:

```
obj = ClassificationDiscriminant.fit(meas,species);
M = margin(obj,meas,species);
M(end-10:end)
```

```
ans =
    0.9983
    1.0000
```

CompactClassificationDiscriminant.margin

0.9991
0.9978
1.0000
1.0000
0.9999
0.9882
0.9937
1.0000
0.9649

See Also

`ClassificationDiscriminant` | `edge` | `loss` | `predict`

How To

- “Discriminant Analysis” on page 12-3

CompactClassificationEnsemble.margin

Purpose

Classification margins

Syntax

`M = margin(ens,X,Y)`
`M = margin(ens,X,Y,Name,Value)`

Description

`M = margin(ens,X,Y)` returns the classification margin for the predictions of `ens` on data `X`, when the true classifications are `Y`.

`M = margin(ens,X,Y,Name,Value)` calculates margin with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

Classification ensemble created with `fitensemble`, or a compact classification ensemble created with `compact`.

X

Matrix of data to classify. Each row of `X` represents one observation, and each column represents one predictor. `X` must have the same number of columns as the data used to train `ens`. `X` should have the same number of rows as the number of elements in `Y`.

Y

Classification of `X`. `Y` should be of the same type as the classification used to train `ens`, and its number of elements should equal the number of rows of `X`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

CompactClassificationEnsemble.margin

Indices of weak learners in the ensemble ranging from 1 to `ens.NTrained`. `oobEdge` uses only these learners for calculating loss.

Default: `1:NTrained`

UseObsForLearner

A logical matrix of size N-by-T, where:

- N is the number of rows of X.
- T is the number of weak learners in `ens`.

When `UseObsForLearner(i, j)` is `true`, learner `j` is used in predicting the class of row `i` of X.

Default: `true(N,T)`

Output Arguments

M

A numeric column vector with the same number of rows as X. Each row of M gives the classification margin for that row of X.

Definitions

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix X.

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

Examples

Find the margin for classifying an average flower from the Fisheriris data as 'versicolor':

```
load fisheriris % X = meas, Y = species
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
flower = mean(meas);
predict(ens,flower)
```

```
ans =
    'versicolor'
```

```
margin(ens,mean(meas),'versicolor')
```

```
ans =
    3.2140
```

See Also

[predict](#) | [edge](#) | [loss](#)

CompactClassificationTree.margin

Purpose Classification margins

Syntax `m = margin(tree,X,Y)`

Description `m = margin(tree,X,Y)` returns the classification margins for the matrix of predictors `X` and class labels `Y`. For the definition, see “Margin” on page 20-1270.

Input Arguments

tree

A classification tree created by `ClassificationTree.fit`, or a compact classification tree created by `compact`.

X

A matrix where each row represents an observation, and each column represents a predictor. The number of columns in `X` must equal the number of predictors in `tree`.

Y

Class labels, with the same data type as exists in `tree`.

Output Arguments

m

A numeric column vector of length `size(X,1)`. Each entry in `m` represents the margin for the corresponding rows of `X` and (true class) `Y`, computed using `tree`.

Definitions

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `X`.

Score (tree)

For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that

CompactClassificationTree.margin

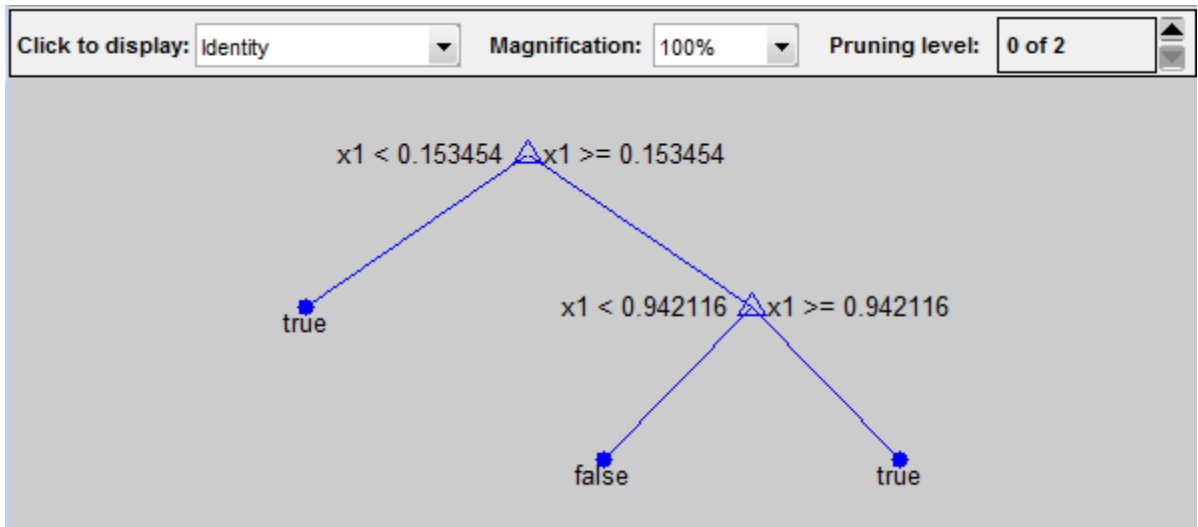
lead to that node with the classification, divided by the number of training sequences that lead to that node.

For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```

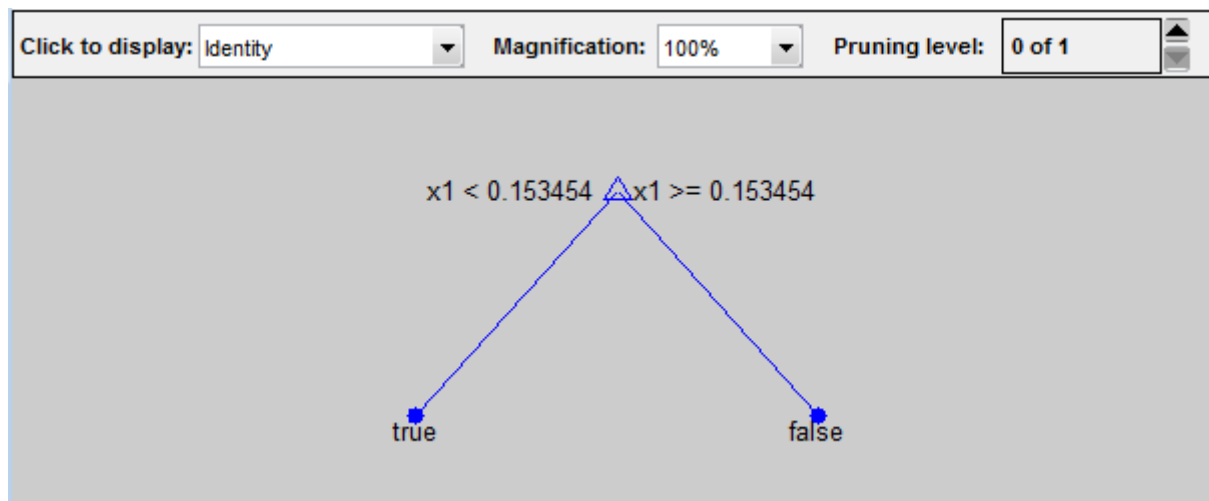


2

Prune the tree:

```
tree1 = prune(tree,'level',1);
view(tree1,'mode','graph')
```

CompactClassificationTree.margin



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
    0.9059    0.0941    0.8147  
    0.9059    0.0941    0.9058  
         0    1.0000    0.1270  
    0.9059    0.0941    0.9134  
    0.9059    0.0941    0.6324  
         0    1.0000    0.0975  
    0.9059    0.0941    0.2785
```

```
0.9059    0.0941    0.5469
0.9059    0.0941    0.9575
0.9059    0.0941    0.9649
```

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range (.95, 1) instead of the expected 5 observations.

Examples

Compute the classification margin for the Fisher iris data, trained on its first two columns of data, and view the last 10 entries:

```
load fisheriris
X = meas(:,1:2);
tree = ClassificationTree.fit(X,species);
M = margin(tree,X,species);
M(end-10:end)

ans =
    0.1111
    0.1111
    0.1111
   -0.2857
    0.6364
    0.6364
    0.1111
    0.7500
    1.0000
    0.6364
    0.2000
```

The classification tree trained on all the data is better:

```
tree = ClassificationTree.fit(meas,species);
M = margin(tree,meas,species);
M(end-10:end)
```

CompactClassificationTree.margin

```
ans =  
  0.9565  
  0.9565  
  0.9565  
  0.9565  
  0.9565  
  0.9565  
  0.9565  
  0.9565  
  0.9565  
  0.9565  
  0.9565
```

See Also

[predict](#) | [loss](#) | [edge](#)

Purpose

Classification margin

Syntax

```
mar = margin(B,X,Y)
mar = margin(B,X,Y, 'param1',val1, 'param2',val2, ...)
```

Description

`mar = margin(B,X,Y)` computes the classification margins for predictors X given true response Y . The Y can be either a numeric vector, character matrix, cell array of strings, categorical vector or logical vector. `mar` is a numeric array of size `Nobs`-by-`NTrees`, where `Nobs` is the number of rows of X and Y , and `NTrees` is the number of trees in the ensemble B . For observation I and tree J , `mar(I,J)` is the difference between the score for the true class and the largest score for other classes. This method is available for classification ensembles only.

`mar = margin(B,X,Y, 'param1',val1, 'param2',val2, ...)` specifies optional parameter name/value pairs:

- 'mode' String indicating how the method computes errors. If set to 'cumulative' (default), `margin` computes cumulative errors and `mar` is an `Nobs`-by-`NTrees` matrix, where the first column gives error from `trees(1)`, second column gives error from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to 'individual', `mar` is a `Nobs`-by-`NTrees` matrix, where each element is an error from each tree in the ensemble. If set to 'ensemble', `mar` a single column of length `Nobs` showing the cumulative margins for the entire ensemble.
- 'trees' Vector of indices indicating what trees to include in this calculation. By default, this argument is set to 'all' and the method uses all trees. If 'trees' is a numeric vector, the method returns a vector of length `NTrees` for 'cumulative' and 'individual' modes, where `NTrees` is the number of elements in the input vector, and a scalar for 'ensemble' mode. For example, in the 'cumulative' mode, the first element

CompactTreeBagger.margin

gives error from `trees(1)`, the second element gives error from `trees(1:2)` etc.

- 'treeweights' Vector of tree weights. This vector must have the same length as the 'trees' vector. The method uses these weights to combine output from the specified trees by taking a weighted average instead of the simple non-weighted majority vote. You cannot use this argument in the 'individual' mode.
- 'useifort' Logical matrix of size Nobs-by-NTrees indicating which trees should be used to make predictions for each observation. By default the method uses all trees for all observations.

See Also

`TreeBagger.margin`

Purpose

Classification margin

Syntax

```
mar = margin(B,X,Y)
mar = margin(B,X,Y, 'param1',val1, 'param2',val2, ...)
```

Description

`mar = margin(B,X,Y)` computes the classification margins for predictors X given true response Y . The Y can be either a numeric vector, character matrix, cell array of strings, categorical vector or logical vector. `mar` is a numeric array of size `Nobs-by-NTrees`, where `Nobs` is the number of rows of X and Y , and `NTrees` is the number of trees in the ensemble B . For observation I and tree J , `mar(I,J)` is the difference between the score for the true class and the largest score for other classes. This method is available for classification ensembles only.

`mar = margin(B,X,Y, 'param1',val1, 'param2',val2, ...)` specifies optional parameter name/value pairs:

- 'mode' String indicating how the method computes errors. If set to 'cumulative' (default), `margin` computes cumulative errors and `mar` is an `Nobs-by-NTrees` matrix, where the first column gives error from `trees(1)`, second column gives error from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to 'individual', `mar` is a `Nobs-by-NTrees` matrix, where each element is an error from each tree in the ensemble. If set to 'ensemble', `mar` a single column of length `Nobs` showing the cumulative margins for the entire ensemble.
- 'trees' Vector of indices indicating what trees to include in this calculation. By default, this argument is set to 'all' and the method uses all trees. If 'trees' is a numeric vector, the method returns a vector of length `NTrees` for 'cumulative' and 'individual' modes, where `NTrees` is the number of elements in the input vector, and a scalar for 'ensemble' mode. For example, in the 'cumulative' mode, the first element

TreeBagger.margin

gives error from `trees(1)`, the second element gives error from `trees(1:2)` etc.

'treeweights' Vector of tree weights. This vector must have the same length as the 'trees' vector. The method uses these weights to combine output from the specified trees by taking a weighted average instead of the simple non-weighted majority vote. You cannot use this argument in the 'individual' mode.

'useifort' Logical matrix of size Nobs-by-NTrees indicating which trees should be used to make predictions for each observation. By default the method uses all trees for all observations.

See Also

`CompactTreeBagger.margin`

Purpose	Convert matrix to dataset array
Syntax	<pre>ds = mat2dataset(X) ds = mat2dataset(X,Name,Value)</pre>
Description	<p><code>ds = mat2dataset(X)</code> converts a matrix to a dataset array.</p> <p><code>ds = mat2dataset(X,Name,Value)</code> performs the conversion using additional options specified by one or more <code>Name,Value</code> pair arguments.</p>
Input Arguments	<p>X - Input matrix matrix</p> <p>Input matrix to convert to a dataset array, specified as an M-by-N numeric matrix. Each column of X becomes a variable in the output M-by-N dataset array.</p> <p>Data Types single double</p> <p>Name-Value Pair Arguments</p> <p>Specify optional comma-separated pairs of <code>Name,Value</code> arguments, where <code>Name</code> is the argument name and <code>Value</code> is the corresponding value. <code>Name</code> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <code>Name1,Value1,...,NameN,ValueN</code>.</p> <p>Example: <code>'NumCols',[1,1,2,1]</code> specifies that the 3rd and 4th columns of the input matrix should be combined into a single variable.</p> <p>VarNames - Variable names for output dataset array cell array of strings</p> <p>Variable names for the output dataset array, specified as the comma-separated pair consisting of <code>'VarNames'</code> and a cell array of strings. You must provide a variable name for each variable in <code>ds</code>. The names must be valid MATLAB identifiers, and must be unique.</p>

Example: 'VarNames', {'myVar1', 'myVar2', 'myVar3'}

ObsNames - Observation names for output dataset array

cell array of strings

Observation names for the output dataset array, specified as the comma-separated pair consisting of 'ObsNames' and a cell array of strings. The names do not need to be valid MATLAB identifiers, but they must be unique.

NumCols - Number of columns for each variable

vector of nonnegative integers

Number of columns for each variable in `ds`, specified as the comma-separated pair consisting of 'NumCols' and a vector of nonnegative integers. When the number of columns for a variable is greater than one, `mat2dataset` combines multiple columns in `X` into a single variable in `ds`. The vector you assign to `NumCols` must sum to `size(X,2)`.

For example, to convert a matrix with eight columns into a dataset array with five variables, specify a vector with five elements that sum to eight, such as 'NumCols', [1,1,3,1,2].

Output Arguments

ds - Output dataset array

dataset array

Output dataset array, returned by default with a variable for each column of `X`, and an observation for each row of `X`. If you specify `NumCols`, then the number of variables in `ds` is equal to the length of the specified vector of column numbers.

Examples

Convert Matrix to Dataset Array

Convert a matrix to a dataset array using the default options.

Load sample data.

```
load('fisheriris')
X = meas;
```

```
size(X)
```

```
ans =
```

```
    150     4
```

Convert the matrix to a dataset array.

```
ds = mat2dataset(X);
```

```
size(ds)
```

```
ans =
```

```
    150     4
```

```
ds(1:5,:)
```

```
ans =
```

X1	X2	X3	X4
5.1	3.5	1.4	0.2
4.9	3	1.4	0.2
4.7	3.2	1.3	0.2
4.6	3.1	1.5	0.2
5	3.6	1.4	0.2

When you do not specify variable names, `mat2dataset` uses the matrix name and column numbers to create default variable names.

Convert Matrix to Dataset Array with Variable Names

Load sample data.

```
load('fisheriris')
```

```
X = meas;
```

```
size(X)
```

```
ans =
```

mat2dataset

```
150    4
```

Convert the matrix to a dataset array, providing a variable name for each of the four column of X.

```
ds = mat2dataset(X, 'VarNames', {'SLength', 'SWidth', 'PLength', 'PWidth'});  
size(ds)
```

```
ans =
```

```
150    4
```

```
ds(1:5, :)
```

```
ans =
```

SWidth	SLength	PWidth	PLength
5.1	3.5	1.4	0.2
4.9	3	1.4	0.2
4.7	3.2	1.3	0.2
4.6	3.1	1.5	0.2
5	3.6	1.4	0.2

Create a Dataset Array with Multicolumn Variables

Convert a matrix to a dataset array containing multicolumn variables.

Load sample data.

```
load('fisheriris')  
X = meas;  
size(X)
```

```
ans =
```

```
150    4
```

Convert the matrix to a dataset array, combining the sepal measurements (the first two columns) into one variable named

SepalMeas, and the petal measurements (third and fourth columns) into one variable names PetalMeas.

```
ds = mat2dataset(X, 'NumCols', [2,2], 'VarNames', {'SepalMeas', 'PetalMeas'})
ds(1:5, :)
```

```
ans =
```

SepalMeas		PetalMeas	
5.1	3.5	1.4	0.2
4.9	3	1.4	0.2
4.7	3.2	1.3	0.2
4.6	3.1	1.5	0.2
5	3.6	1.4	0.2

The output dataset array has 150 observations and 2 variables.

```
size(ds)
```

```
ans =
```

```
150    2
```

See Also

[cell2dataset](#) [dataset](#) | | [struct2dataset](#)

Related Examples

- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Create a Dataset Array from a File” on page 2-92

Concepts

- “Dataset Arrays” on page 2-156

mdscale

Purpose Nonclassical multidimensional scaling

Syntax

```
Y = mdscale(D,p)
[Y,stress] = mdscale(D,p)
[Y,stress,disparities] = mdscale(D,p)
[...] = mdscale(D,p,'Name',value)
```

Description `Y = mdscale(D,p)` performs nonmetric multidimensional scaling on the n -by- n dissimilarity matrix D , and returns Y , a configuration of n points (rows) in p dimensions (columns). The Euclidean distances between points in Y approximate a monotonic transformation of the corresponding dissimilarities in D . By default, `mdscale` uses Kruskal's normalized stress1 criterion.

You can specify D as either a full n -by- n matrix, or in upper triangle form such as is output by `pdist`. A full dissimilarity matrix must be real and symmetric, and have zeros along the diagonal and non-negative elements everywhere else. A dissimilarity matrix in upper triangle form must have real, non-negative entries. `mdscale` treats NaNs in D as missing values, and ignores those elements. `Inf` is not accepted.

You can also specify D as a full similarity matrix, with ones along the diagonal and all other elements less than one. `mdscale` transforms a similarity matrix to a dissimilarity matrix in such a way that distances between the points returned in Y approximate $\sqrt{1-D}$. To use a different transformation, transform the similarities prior to calling `mdscale`.

`[Y,stress] = mdscale(D,p)` returns the minimized stress, i.e., the stress evaluated at Y .

`[Y,stress,disparities] = mdscale(D,p)` returns the disparities, that is, the monotonic transformation of the dissimilarities D .

`[...] = mdscale(D,p,'Name',value)` specifies one or more optional parameter name/value pairs that control further details of `mdscale`. Specify *Name* in single quotes. Available parameters are

- **Criterion**— The goodness-of-fit criterion to minimize. This also determines the type of scaling, either non-metric or metric, that mdscale performs. Choices for non-metric scaling are:
 - 'stress' — Stress normalized by the sum of squares of the inter-point distances, also known as stress1. This is the default.
 - 'sstress' — Squared stress, normalized with the sum of 4th powers of the inter-point distances.

Choices for metric scaling are:

- 'metricstress' — Stress, normalized with the sum of squares of the dissimilarities.
 - 'metricsstress' — Squared stress, normalized with the sum of 4th powers of the dissimilarities.
 - 'sammon' — Sammon's nonlinear mapping criterion. Off-diagonal dissimilarities must be strictly positive with this criterion.
 - 'strain' — A criterion equivalent to that used in classical multidimensional scaling.
- **Weights** — A matrix or vector the same size as D, containing nonnegative dissimilarity weights. You can use these to weight the contribution of the corresponding elements of D in computing and minimizing stress. Elements of D corresponding to zero weights are effectively ignored.

Note When you specify weights as a full matrix, its diagonal elements are ignored and have no effect, since the corresponding diagonal elements of D do not enter into the stress calculation.

- **Start** — Method used to choose the initial configuration of points for Y. The choices are

mdscale

- 'cmdscale' — Use the classical multidimensional scaling solution. This is the default. 'cmdscale' is not valid when there are zero weights.
- 'random' — Choose locations randomly from an appropriately scaled p -dimensional normal distribution with uncorrelated coordinates.
- An n -by- p matrix of initial locations, where n is the size of the matrix D and p is the number of columns of the output matrix Y . In this case, you can pass in `[]` for p and `mdscale` infers p from the second dimension of the matrix. You can also supply a 3-D array, implying a value for 'Replicates' from the array's third dimension.
- Replicates — Number of times to repeat the scaling, each with a new initial configuration. The default is 1.
- Options — Options for the iterative algorithm used to minimize the fitting criterion. Pass in an options structure created by `statset`. For example,

```
opts = statset(param1, val1, param2, val2, ...);  
[...] = mdscale(..., 'Options', opts)
```

The choices of `statset` parameters are

- 'Display' — Level of display output. The choices are 'off' (the default), 'iter', and 'final'.
- 'MaxIter' — Maximum number of iterations allowed. The default is 200.
- 'TolFun' — Termination tolerance for the stress criterion and its gradient. The default is $1e-4$.
- 'TolX' — Termination tolerance for the configuration location step size. The default is $1e-4$.

Examples

```
load cereal.mat  
X = [Calories Protein Fat Sodium Fiber ...
```



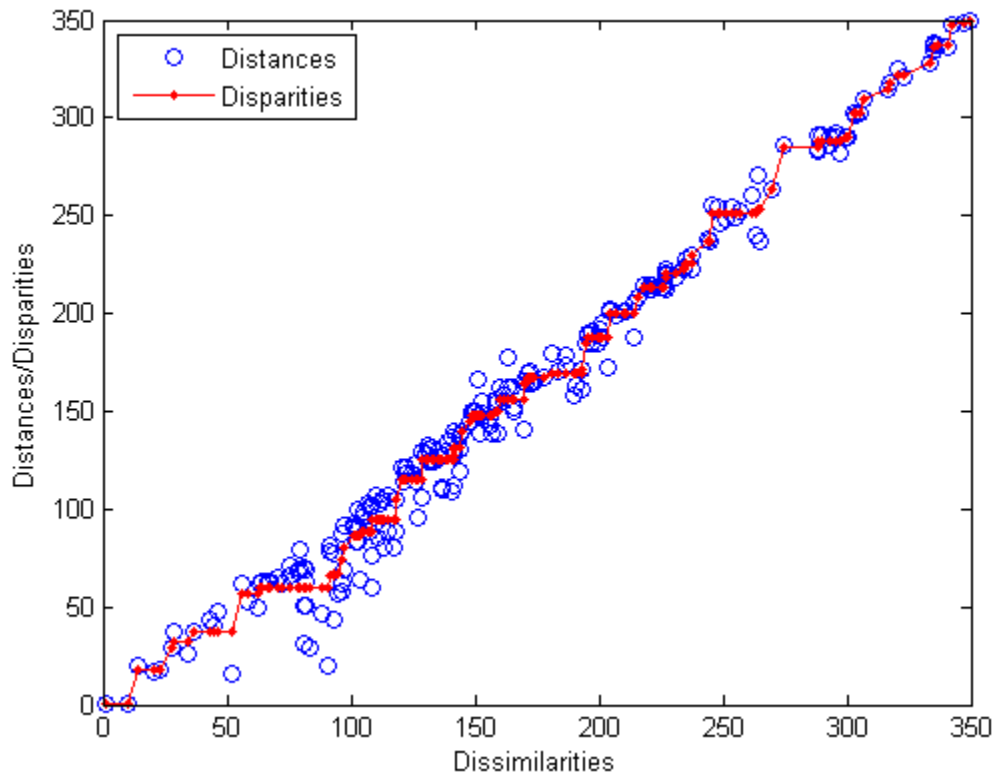
```
Carbo Sugars Shelf Potass Vitamins];

% Take a subset from a single manufacturer.
X = X(strcmp('K',cellstr(Mfg)),:);

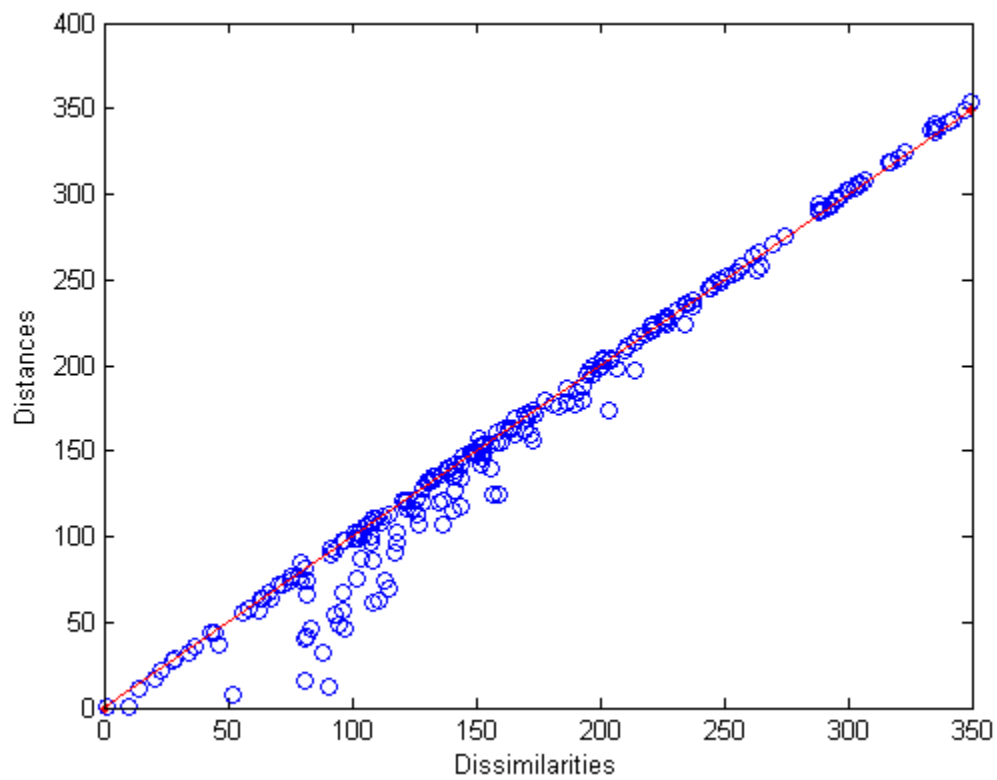
% Create a dissimilarity matrix.
dissimilarities = pdist(X);

% Use non-metric scaling to recreate the data in 2D,
% and make a Shepard plot of the results.
[Y, stress, disparities] = mdscale(dissimilarities, 2);
distances = pdist(Y);
[dum, ord] = sortrows([disparities(:) dissimilarities(:)]);
plot(dissimilarities(distances, 'bo', ...
dissimilarities(ord), disparities(ord), 'r.-');
xlabel('Dissimilarities'); ylabel('Distances/Disparities')
legend({'Distances' 'Disparities'}, 'Location', 'NW');
```

mdscale



```
% Do metric scaling on the same dissimilarities.  
figure  
[Y, stress] = ...  
mdscale(dissimilarities, 2, 'criterion', 'metricsstress');  
distances = pdist(Y);  
plot(dissimilarities, distances, 'bo', ...  
[0 max(dissimilarities)], [0 max(dissimilarities)], 'r.-');  
xlabel('Dissimilarities'); ylabel('Distances')
```

**See Also**`cmdscale | pdist | statset`

CompactTreeBagger.mdsProx

Purpose Multidimensional scaling of proximity matrix

Syntax `[SC,EIGEN] = mdsProx(B,X)`
`[SC,EIGEN] = mdsProx(B,X,'param1',val1,'param2',val2,...)`

Description `[SC,EIGEN] = mdsProx(B,X)` applies classical multidimensional scaling to the proximity matrix computed for the data in the matrix `X`, and returns scaled coordinates `SC` and eigenvalues `EIGEN` of the scaling transformation. The method applies multidimensional scaling to the matrix of distances defined as `1-prox`, where `prox` is the proximity matrix returned by the `proximity` method.

You can supply the proximity matrix directly by using the `'data'` parameter.

`[SC,EIGEN] = mdsProx(B,X,'param1',val1,'param2',val2,...)` specifies optional parameter name/value pairs:

- `'data'` Flag indicating how the method treats the `X` input argument. If set to `'predictors'` (default), `mdsProx` assumes `X` to be a matrix of predictors and used for computation of the proximity matrix. If set to `'proximity'`, the method treats `X` as a proximity matrix returned by the `proximity` method.
- `'colors'` If you supply this argument, `mdsProx` makes overlaid scatter plots of two scaled coordinates using specified colors for different classes. You must supply the colors as a string with one character for each color. If there are more classes in the data than characters in the supplied string, `mdsProx` only plots the first `C` classes, where `C` is the length of the string. For regression or if you do not provide the vector of true class labels, the method uses the first color for all observations in `X`.

- 'labels' Vector of true class labels for a classification ensemble. True class labels can be either a numeric vector, character matrix, or cell array of strings. If supplied, this vector must have as many elements as there are observations (rows) in X. This argument has no effect unless you also supply the 'colors' argument.
- 'mdscoords' Indices of the two scaled coordinates to plot. By default, mdsProx makes a scatter plot of the first and second scaled coordinates which correspond to the two largest eigenvalues. You can specify any other two or three indices not exceeding the dimensionality of the scaled data. This argument has no effect unless you also supply the 'colors' argument.

See Also

[cmdscale](#) | [TreeBagger.mdsProx](#) | [proximity](#)

TreeBagger.mdsProx

Purpose Multidimensional scaling of proximity matrix

Syntax `[S,E] = mdsProx(B)`
`[S,E] = mdsProx(B, 'param1', val1, 'param2', val2, ...)`

Description `[S,E] = mdsProx(B)` returns scaled coordinates, S, and eigenvalues, E, for the proximity matrix in the ensemble B. An earlier call to `fillProximities(B)` must create the proximity matrix.

`[S,E] = mdsProx(B, 'param1', val1, 'param2', val2, ...)` specifies optional parameter name/value pairs:

- 'keep' Array of indices of observations in the training data to use for multidimensional scaling. By default, this argument is set to 'all'. If you provide numeric or logical indices, the method uses only the subset of the training data specified by these indices to compute the scaled coordinates and eigenvalues.
- 'colors' If you supply this argument, `mdsProx` makes overlaid scatter plots of two scaled coordinates using specified colors for different classes. You must supply the colors as a string with one character for each color. If there are more classes in the data than characters in the supplied string, `mdsProx` only plots the first C classes, where C is the length of the string. For regression or if you do not provide the vector of true class labels, the method uses the first color for all observations in X.
- 'mdscoords' Indices of the two scaled coordinates to plot. By default, `mdsProx` makes a scatter plot of the first and second scaled coordinates which correspond to the two largest eigenvalues. You can specify any other two or three indices not exceeding the dimensionality of the scaled data. This argument has no effect unless you also supply the 'colors' argument.

See Also `cmdscale` | `CompactTreeBagger.mdsProx` | `fillProximities`

Purpose	Return mean of ProbDistUnivParam object	
Syntax	$M = \text{mean}(PD)$	
Description	$M = \text{mean}(PD)$ returns M , the mean of the ProbDistUnivParam object PD .	
Input Arguments	PD	An object of the class ProbDistUnivParam.
Output Arguments	M	The mean of the ProbDistUnivParam object PD .
See Also	mean	

CompactTreeBagger.meanMargin

Purpose Mean classification margin

Syntax
`mar = meanMargin(B,X,Y)`
`mar = meanMargin(B,X,Y, 'param1',val1, 'param2',val2,...)`

Description `mar = meanMargin(B,X,Y)` computes average classification margins for predictors `X` given true response `Y`. The `Y` can be either a numeric vector, character matrix, cell array of strings, categorical vector or logical vector. `meanMargin` averages the margins over all observations (rows) in `X` for each tree. `mar` is a matrix of size 1-by-`NTrees`, where `NTrees` is the number of trees in the ensemble `B`. This method is available for classification ensembles only.

`mar = meanMargin(B,X,Y, 'param1',val1, 'param2',val2,...)` specifies optional parameter name/value pairs:

`'mode'` String indicating how `meanMargin` computes errors. If set to `'cumulative'` (default), is a vector of length `NTrees` where the first element gives mean margin from `trees(1)`, second column gives mean margins from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to `'individual'`, `mar` is a vector of length `NTrees`, where each element is a mean margin from each tree in the ensemble. If set to `'ensemble'`, `mar` is a scalar showing the cumulative mean margin for the entire ensemble.

`'trees'` Vector of indices indicating what trees to include in this calculation. By default, this argument is set to `'all'` and the method uses all trees. If `'trees'` is a numeric vector, the method returns a vector of length `NTrees` for `'cumulative'` and `'individual'` modes, where `NTrees` is the number of elements in the input vector, and a scalar for `'ensemble'` mode. For example, in the `'cumulative'` mode, the first element

gives mean margin from `trees(1)`, the second element gives mean margin from `trees(1:2)` etc.

'`treeweights`' Vector of tree weights. This vector must have the same length as the '`trees`' vector. `meanMargin` uses these weights to combine output from the specified trees by taking a weighted average instead of the simple nonweighted majority vote. You cannot use this argument in the '`individual`' mode.

See Also

`TreeBagger.meanMargin`

TreeBagger.meanMargin

Purpose Mean classification margin

Syntax
`mar = meanMargin(B,X,Y)`
`mar = meanMargin(B,X,Y, 'param1',val1, 'param2',val2,...)`

Description `mar = meanMargin(B,X,Y)` computes average classification margins for predictors `X` given true response `Y`. The `Y` can be either a numeric vector, character matrix, cell array of strings, categorical vector or logical vector. `meanMargin` averages the margins over all observations (rows) in `X` for each tree. `mar` is a matrix of size 1-by-`NTrees`, where `NTrees` is the number of trees in the ensemble `B`. This method is available for classification ensembles only.

`mar = meanMargin(B,X,Y, 'param1',val1, 'param2',val2,...)` specifies optional parameter name/value pairs:

'mode' String indicating how `meanMargin` computes errors. If set to 'cumulative' (default), is a vector of length `NTrees` where the first element gives mean margin from `trees(1)`, second column gives mean margins from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to 'individual', `mar` is a vector of length `NTrees`, where each element is a mean margin from each tree in the ensemble. If set to 'ensemble', `mar` is a scalar showing the cumulative mean margin for the entire ensemble.

'trees' Vector of indices indicating what trees to include in this calculation. By default, this argument is set to 'all' and the method uses all trees. If 'trees' is a numeric vector, the method returns a vector of length `NTrees` for 'cumulative' and 'individual' modes, where `NTrees` is the number of elements in the input vector, and a scalar for 'ensemble' mode. For example, in the 'cumulative' mode, the first element

gives mean margin from `trees(1)`, the second element gives mean margin from `trees(1:2)` etc.

'`treeweights`' Vector of tree weights. This vector must have the same length as the '`trees`' vector. `meanMargin` uses these weights to combine output from the specified trees by taking a weighted average instead of the simple nonweighted majority vote. You cannot use this argument in the '`individual`' mode.

See Also

`CompactTreeBagger.meanMargin`

classregtree.meansurrvarassoc

Purpose Mean predictive measure of association for surrogate splits in decision tree

Syntax MA = meansurrvarassoc(T)
MA = meansurrvarassoc(T,N)

Description MA = meansurrvarassoc(T) returns a p -by- p matrix, MA, with predictive measures of association for p predictors. Element MA(i,j) is the predictive measure of association averaged over surrogate splits on predictor j for which predictor i is the optimal split predictor. This average is computed by summing positive values of the predictive measure of association over optimal splits on predictor i and surrogate splits on predictor j and dividing by the total number of optimal splits on predictor i , including splits for which the predictive measure of association between predictors i and j is negative.

MA = meansurrvarassoc(T,N) takes an array N of node numbers and returns the predictive measure of association averaged over the specified nodes.

See Also classregtree | surrcutvar | surrvarassoc | surrcutcategories | surrcuttype | surrcutpoint | surrcutflip

CompactClassificationTree.meanSurrVarAssoc

Purpose	Mean predictive measure of association for surrogate splits in decision tree
Syntax	<pre>ma = meanSurrVarAssoc(tree) ma = meanSurrVarAssoc(tree,N)</pre>
Description	<p><code>ma = meanSurrVarAssoc(tree)</code> returns a matrix of predictive measures of association for the predictors in <code>tree</code>.</p> <p><code>ma = meanSurrVarAssoc(tree,N)</code> returns a matrix of predictive measures of association averaged over the nodes in vector <code>N</code>.</p>
Input Arguments	<p>tree</p> <p>A classification tree constructed with <code>ClassificationTree.fit</code>, or a compact regression tree constructed with <code>compact</code>.</p> <p>N</p> <p>Vector of node numbers in <code>tree</code>.</p>
Output Arguments	<p>ma</p> <ul style="list-style-type: none">• <code>ma = meanSurrVarAssoc(tree)</code> returns a P-by-P matrix, where P is the number of predictors in <code>tree</code>. <code>ma(i,j)</code> is the predictive measure of association between the optimal split on variable <code>i</code> and a surrogate split on variable <code>j</code>. See “Predictive Measure of Association” on page 20-1299.• <code>ma = meanSurrVarAssoc(tree,N)</code> returns a P-by-P representing the predictive measure of association between variables averaged over nodes in the vector <code>N</code>. <code>N</code> contains node numbers from 1 to <code>max(tree.NumNodes)</code>.
Definitions	<p>Predictive Measure of Association</p> <p>The predictive measure of association between the optimal split on variable <code>i</code> and a surrogate split on variable <code>j</code> is:</p>

CompactClassificationTree.meanSurrVarAssoc

$$\lambda_{i,j} = \frac{\min(P_L, P_R) - (1 - P_{L_i L_j} - P_{R_i R_j})}{\min(P_L, P_R)}.$$

Here

- P_L and P_R are the node probabilities for the optimal split of node i into Left and Right nodes respectively.
- $P_{L_i L_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Left.
- $P_{R_i R_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Right.

Clearly, $\lambda_{i,j}$ lies from $-\infty$ to 1. Variable j is a worthwhile surrogate split for variable i if $\lambda_{i,j} > 0$.

Element $\text{ma}(i, j)$ is the predictive measure of association averaged over surrogate splits on predictor j for which predictor i is the optimal split predictor. This average is computed by summing positive values of the predictive measure of association over optimal splits on predictor i and surrogate splits on predictor j and dividing by the total number of optimal splits on predictor i , including splits for which the predictive measure of association between predictors i and j is negative.

Examples

Find the mean predictive measure of association between the variables in the Fisher iris data:

```
load fisheriris
obj = ClassificationTree.fit(meas,species,'surrogate','on');
msva = meanSurrVarAssoc(obj)
```

```
msva =
    1.0000         0         0         0
         0    1.0000         0         0
    0.4633    0.2500    1.0000    0.5000
```

CompactClassificationTree.meanSurrVarAssoc

```
0.2065    0.1413    0.4022    1.0000
```

Find the mean predictive measure of association averaged over the odd-numbered nodes in obj:

```
N = 1:2:obj.NumNodes;  
msva = meanSurrVarAssoc(obj,N)
```

```
msva =  
    1.0000         0         0         0  
         0    1.0000         0         0  
    0.7600    0.5000    1.0000    1.0000  
    0.4130    0.2826    0.8043    1.0000
```

See Also

ClassificationTree

CompactRegressionTree.meanSurrVarAssoc

Purpose Mean predictive measure of association for surrogate splits in decision tree

Syntax `ma = meanSurrVarAssoc(tree)`
`ma = meanSurrVarAssoc(tree,N)`

Description `ma = meanSurrVarAssoc(tree)` returns a matrix of predictive measures of association for the predictors in `tree`.
`ma = meanSurrVarAssoc(tree,N)` returns a matrix of predictive measures of association averaged over the nodes in vector `N`.

Input Arguments **tree**
A regression tree constructed with `RegressionTree.fit`, or a compact regression tree constructed with `compact`.

N
Vector of node numbers in `tree`.

Output Arguments **ma**

- `ma = meanSurrVarAssoc(tree)` returns a P-by-P matrix, where P is the number of predictors in `tree`. `ma(i,j)` is the predictive measure of association between the optimal split on variable `i` and a surrogate split on variable `j`. See “Predictive Measure of Association” on page 20-1302.
- `ma = meanSurrVarAssoc(tree,N)` returns a P-by-P representing the predictive measure of association between variables averaged over nodes in the vector `N`. `N` contains node numbers from 1 to `max(tree.NumNodes)`.

Definitions **Predictive Measure of Association**

The predictive measure of association between the optimal split on variable `i` and a surrogate split on variable `j` is:

$$\lambda_{i,j} = \frac{\min(P_L, P_R) - (1 - P_{L_i L_j} - P_{R_i R_j})}{\min(P_L, P_R)}.$$

Here

- P_L and P_R are the node probabilities for the optimal split of node i into Left and Right nodes respectively.
- $P_{L_i L_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Left.
- $P_{R_i R_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Right.

Clearly, $\lambda_{i,j}$ lies from $-\infty$ to 1. Variable j is a worthwhile surrogate split for variable i if $\lambda_{i,j} > 0$.

Element $\text{ma}(i, j)$ is the predictive measure of association averaged over surrogate splits on predictor j for which predictor i is the optimal split predictor. This average is computed by summing positive values of the predictive measure of association over optimal splits on predictor i and surrogate splits on predictor j and dividing by the total number of optimal splits on predictor i , including splits for which the predictive measure of association between predictors i and j is negative.

Examples

Find the mean predictive measure of association between the Displacement, Horsepower, and Weight variables in the carsmall data:

```
load carsmall
X = [Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG, 'surrogate', 'on');
ma = meanSurrVarAssoc(tree)
```

```
ma =
    1.0000    0.2708    0.3854
    0.4764    1.0000    0.4568
```

CompactRegressionTree.meanSurrVarAssoc

```
0.3472    0.2326    1.0000
```

Find the mean predictive measure of association averaged over the odd-numbered nodes in tree:

```
N = 1:2:tree.NumNodes;  
ma = meanSurrVarAssoc(tree,N)
```

```
ma =  
    1.0000    0.2500    0.3750  
    0.5910    1.0000    0.5861  
    0.5000    0.2361    1.0000
```

See Also

[prune](#) | [RegressionTree](#)

Purpose Return median of ProbDistUnivKernel object

Syntax $M = \text{median}(PD)$

Description $M = \text{median}(PD)$ returns M , the median of the ProbDistUnivKernel object PD .

Input Arguments PD An object of the class ProbDistUnivKernel.

Output Arguments M The median of the ProbDistUnivKernel object PD .

See Also median

ProbDistUnivParam.median

Purpose Return median of ProbDistUnivParam object

Syntax $M = \text{median}(PD)$

Description $M = \text{median}(PD)$ returns M , the median of the ProbDistUnivParam object PD .

Input Arguments PD An object of the class ProbDistUnivParam.

Output Arguments M The median of the ProbDistUnivParam object PD .

See Also median

TreeBagger.MergeLeaves property

Purpose	Flag to merge leaves that do not improve risk
Description	The MergeLeaves property is true if decision trees have their leaves with the same parent merged for splits that do not decrease the total risk, and false otherwise. The default value is false.
See Also	<code>classregtree</code>

ordinal.mergelevels

Purpose Merge levels

Syntax B = mergelevels(A,oldlevels,newlevel)
B = mergelevels(A,oldlevels)

Description B = mergelevels(A,oldlevels,newlevel) merges two or more levels of the categorical array A into a single new level. oldlevels is a cell array of strings or a 2-D character matrix that specifies the levels to be merged. Any elements of A that have levels in oldlevels are assigned the new level in the corresponding elements of B. newlevel is a character string that specifies the label for the new level. For ordinal arrays, the levels of A specified by oldlevels must be consecutive, and mergelevels inserts the new level to preserve the order of the levels.

B = mergelevels(A,oldlevels) merges two or more levels of A. For nominal arrays, mergelevels uses the first label in oldlevels as the label for the new level. For ordinal arrays, mergelevels uses the label corresponding to the lowest level in oldlevels as the label for the new level.

Examples

Example 1

For nominal data:

```
load fisheriris
species = nominal(species);
species = mergelevels(species,...
                      {'setosa','virginica'},'parent');
species = setlabels(species,'hybrid','versicolor');
getlabels(species)
ans =
    'hybrid'    'parent'
```

Example 2

For ordinal data:

```
A = ordinal([1 2 3 2 1],{'lo','med','hi'})
```

```
A =  
    lo      med      hi      med      lo
```

```
A = mergelevels(A,{'lo','med'},'bad')
```

```
A =  
    bad      bad      hi      bad      bad
```

See Also

[addlevels](#) | [droplevels](#) | [islevel](#) | [reorderlevels](#) | [getlabels](#)

TreeBagger.Method property

Purpose Method used by trees (classification or regression)

Description The Method property is 'classification' for classification ensembles and 'regression' for regression ensembles.

Purpose

Metropolis-Hastings sample

Syntax

```
smp1 = mhsample(start,nsamples,'pdf',pdf,'proppdf',proppdf,  
               'proprnd',proprnd)  
smp1 = mhsample(...,'symmetric',sym)  
smp1 = mhsample(...,'burnin',K)  
smp1 = mhsample(...,'thin',m)  
smp1 = mhsample(...,'nchain',n)  
[smp1,accept] = mhsample(...)
```

Description

`smp1 = mhsample(start,nsamples,'pdf',pdf,'proppdf',proppdf,'proprnd',proprnd)` draws `nsamples` random samples from a target stationary distribution `pdf` using the Metropolis-Hastings algorithm.

`start` is a row vector containing the start value of the Markov Chain, `nsamples` is an integer specifying the number of samples to be generated, and `pdf`, `proppdf`, and `proprnd` are function handles created using `@`. `proppdf` defines the proposal distribution density, and `proprnd` defines the random number generator for the proposal distribution. `pdf` and `proprnd` take one argument as an input with the same type and size as `start`. `proppdf` takes two arguments as inputs with the same type and size as `start`.

`smp1` is a column vector or matrix containing the samples. If the log density function is preferred, `'pdf'` and `'proppdf'` can be replaced with `'logpdf'` and `'logproppdf'`. The density functions used in Metropolis-Hastings algorithm are not necessarily normalized.

The proposal distribution $q(x,y)$ gives the probability density for choosing x as the next point when y is the current point. It is sometimes written as $q(x|y)$.

If the `proppdf` or `logproppdf` satisfies $q(x,y) = q(y,x)$, that is, the proposal distribution is symmetric, `mhsample` implements Random Walk Metropolis-Hastings sampling. If the `proppdf` or `logproppdf` satisfies $q(x,y) = q(x)$, that is, the proposal distribution is independent of current values, `mhsample` implements Independent Metropolis-Hastings sampling.

`smp1 = mhsample(..., 'symmetric', sym)` draws `nsamples` random samples from a target stationary distribution pdf using the Metropolis-Hastings algorithm. `sym` is a logical value that indicates whether the proposal distribution is symmetric. The default value is false, which corresponds to the asymmetric proposal distribution. If `sym` is true, for example, the proposal distribution is symmetric, `proppdf` and `logproppdf` are optional.

`smp1 = mhsample(..., 'burnin', K)` generates a Markov chain with values between the starting point and the k^{th} point omitted in the generated sequence. Values beyond the k^{th} point are kept. `k` is a nonnegative integer with default value of 0.

`smp1 = mhsample(..., 'thin', m)` generates a Markov chain with `m-1` out of `m` values omitted in the generated sequence. `m` is a positive integer with default value of 1.

`smp1 = mhsample(..., 'nchain', n)` generates `n` Markov chains using the Metropolis-Hastings algorithm. `n` is a positive integer with a default value of 1. `smp1` is a matrix containing the samples. The last dimension contains the indices for individual chains.

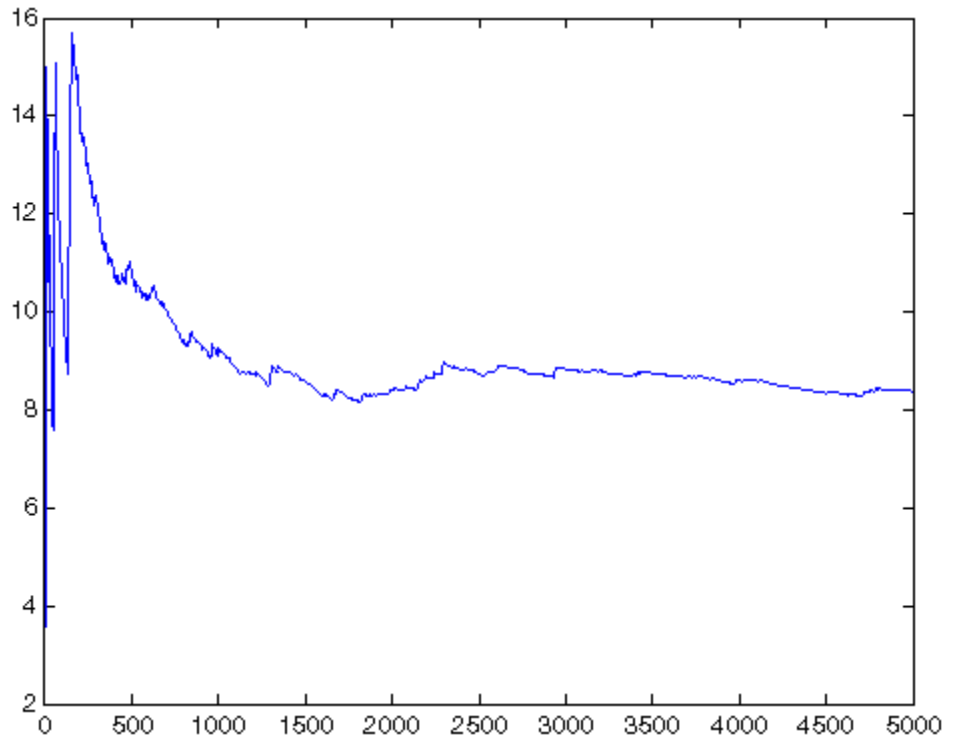
`[smp1, accept] = mhsample(...)` also returns `accept`, the acceptance rate of the proposed distribution. `accept` is a scalar if a single chain is generated and is a vector if multiple chains are generated.

Examples

Estimate the second order moment of a Gamma distribution using the Independent Metropolis-Hastings sampling.

```
alpha = 2.43;
beta = 1;
pdf = @(x)gampdf(x,alpha,beta); %target distribution
proppdf = @(x,y)gampdf(x,floor(alpha),floor(alpha)/alpha);
proprnd = @(x)sum(...
    exprnd(floor(alpha)/alpha,floor(alpha),1));
nsamples = 5000;
smp1 = mhsample(1,nsamples,'pdf',pdf,'proprnd',proprnd,...
    'proppdf',proppdf);
xxhat = cumsum(smp1.^2)./(1:nsamples)';
```

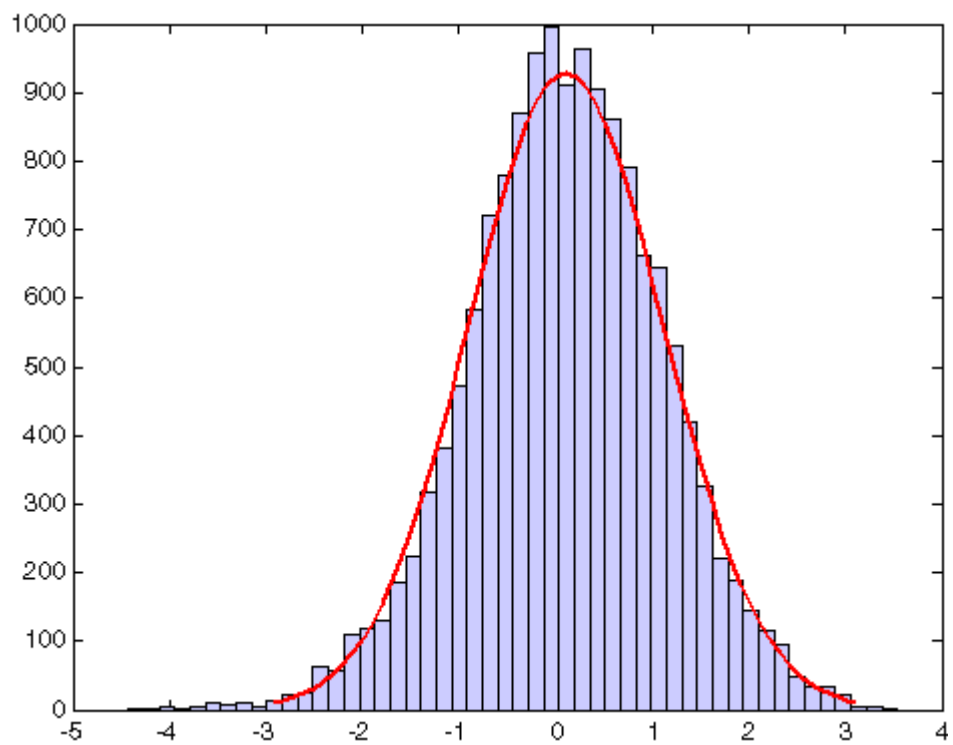
```
plot(1:nsamples,xxhat)
```



Generate random samples from $N(0,1)$ using the Random Walk Metropolis-Hastings sampling.

```
delta = .5;
pdf = @(x) normpdf(x);
proppdf = @(x,y) unifpdf(y-x,-delta,delta);
proprnd = @(x) x + rand*2*delta - delta;
nsamples = 15000;
x = mhsample(1,nsamples,'pdf',pdf,'proprnd',proprnd,'symmetric',1);
histfit(x,50)
h = get(gca,'Children');
set(h(2),'FaceColor',[.8 .8 1])
```

mhsample



See Also

`slicesample` | `rand`

TreeBagger.MinLeaf property

Purpose	Minimum number of observations per tree leaf
Description	The MinLeaf property specifies the minimum number of observations per tree leaf. The default values are 1 for classification and 5 for regression. For <code>classregtree</code> training, the 'minparent' value is set to $2 * \text{MinLeaf}$.
See Also	<code>classregtree</code>

mle

Purpose Maximum likelihood estimates

Syntax

```
phat = mle(data)
[phat,pci] = mle(data)
[...] = mle(data,'distribution',dist)
[...] = mle(data,...,name1,val1,name2,val2,...)
[...] = mle(data,'pdf',pdf,'cdf',cdf,'start',start,...)
[...] = mle(data,'logpdf',logpdf,'logsf',logsf,'start',start,
    ...)
[...] = mle(data,'nloglf',nloglf,'start',start,...)
```

Description `phat = mle(data)` returns maximum likelihood estimates (MLEs) for the parameters of a normal distribution, computed using the sample data in the vector `data`.

`[phat,pci] = mle(data)` returns MLEs and 95% confidence intervals for the parameters.

`[...] = mle(data,'distribution',dist)` computes parameter estimates for the distribution specified by *dist*. Acceptable strings for *dist*, and the returned parameters, are:

name	Distribution	Parameter 1	Parameter 2	Parameter 3
'bernoulli'	"Bernoulli Distribution" on page B-3	p: probability of success for each trial	—	—
'beta' or 'Beta'	"Beta Distribution" on page B-4	a	b	—
'bino' or 'Binomial'	"Binomial Distribution" on page B-7	n: number of trials	p: probability of success for each trial	—

name	Distribution	Parameter 1	Parameter 2	Parameter 3
'birnbaumsaunders'	“Birnbbaum-Saunders Distribution” on page B-10	β	γ	—
'burr' or 'Burr'	“Burr Type XII Distribution” on page B-12	α : scale parameter	c : shape parameter	k : shape parameter
'Discrete Uniform' or 'unid'	“Uniform Distribution (Discrete)” on page B-114	N : maximum observable value	—	—
'exp' or 'Exponential'	“Exponential Distribution” on page B-29	μ : mean	—	—
'ev' or 'Extreme Value'	“Extreme Value Distribution” on page B-32	μ : location parameter	σ : scale parameter	—
'gam' or 'Gamma'	“Gamma Distribution” on page B-40	a : shape parameter	b : scale parameter	—
'gev' or 'Generalized Extreme Value'	“Generalized Extreme Value Distribution” on page B-45	k : shape parameter	σ : scale parameter	μ : location parameter
'gp' or 'Generalized Pareto'	“Generalized Pareto Distribution” on page B-50	k : tail index (shape) parameter	σ : scale parameter	—
'geo' or 'Geometric'	“Geometric Distribution” on page B-54	p : probability parameter	—	—

name	Distribution	Parameter 1	Parameter 2	Parameter 3
'inversegaussian'	"Inverse Gaussian Distribution" on page B-58	μ	λ	—
'logistic'	"Logistic Distribution" on page B-62	μ	σ	—
'loglogistic'	"Loglogistic Distribution" on page B-63	μ	σ	—
'logn' or 'Lognormal'	"Lognormal Distribution" on page B-64	μ	σ	—
'nakagami'	"Nakagami Distribution" on page B-83	μ	ω	—
'nbin' or 'Negative Binomial'	"Negative Binomial Distribution" on page B-85	r: number of successes	p: probability of success in a single trial	—
'norm' or 'Normal'	"Normal Distribution" on page B-96	μ : mean	σ : standard deviation	—
'poiss' or 'Poisson'	"Poisson Distribution" on page B-102	λ : mean	—	—
'rayl' or 'Rayleigh'	"Rayleigh Distribution" on page B-104	b: scale parameter	—	—

name	Distribution	Parameter 1	Parameter 2	Parameter 3
'rician'	“Rician Distribution” on page B-106	s: noncentrality parameter	σ : scale parameter	—
'tlocationscale'	“t Location-Scale Distribution” on page B-110	μ : location parameter	σ : scale parameter	ν : shape parameter
'unif' or 'Uniform'	“Uniform Distribution (Continuous)” on page B-112	a: lower endpoint (minimum)	b: upper endpoint (maximum)	—
'wbl' or 'Weibull'	“Weibull Distribution” on page B-116	a: scale parameter	b: shape parameter	—

[...] = mle(data,...,name1,val1,name2,val2,...) specifies optional argument name/value pairs chosen from the following list.

Name	Value
'censoring'	A Boolean vector of the same size as data, containing ones when the corresponding elements of data are right-censored observations and zeros when the corresponding elements are exact observations. The default is that all observations are observed exactly. Censoring is not supported for all distributions.
'frequency'	A vector of the same size as data, containing nonnegative integer frequencies for the corresponding elements in data. The default is one observation per element of data.

Name	Value
'alpha'	A value between 0 and 1 specifying a confidence level of $100(1 - \alpha)\%$ for pci. The default is 0.05 for 95% confidence.
'ntrials'	A scalar, or a vector of the same size as data, containing the total number of trials for the corresponding element of data. Applies only to the binomial distribution.
'options'	A structure created by a call to <code>statset</code> , containing numerical options for the fitting algorithm. Not applicable to all distributions.

`mle` can also fit custom distributions that you define using distribution functions, in one of three ways.

```
[...] = mle(data, 'pdf', pdf, 'cdf', cdf, 'start', start, ...)
```

returns MLEs for the parameters of the distribution defined by the probability density and cumulative distribution functions `pdf` and `cdf`. `pdf` and `cdf` are function handles created using the @ sign. They accept as inputs a vector `data` and one or more individual distribution parameters, and return vectors of probability density values and cumulative probability values, respectively. If the 'censoring' name/value pair is not present, you can omit the 'cdf' name/value pair. `mle` computes the estimates by numerically maximizing the distribution's log-likelihood, and `start` is a vector containing initial values for the parameters.

```
[...] =  
mle(data, 'logpdf', logpdf, 'logsf', logsf, 'start', start, ...)
```

returns MLEs for the parameters of the distribution defined by the log probability density and log survival functions `logpdf` and `logsf`. `logpdf` and `logsf` are function handles created using the @ sign. They accept as inputs a vector `data` and one or more individual distribution parameters, and return vectors of logged probability density values and logged survival function values, respectively. This form is sometimes more robust to the choice of starting point than using `pdf` and `cdf`

functions. If the 'censoring' name/value pair is not present, you can omit the 'logsf' name/value pair. `start` is a vector containing initial values for the distribution's parameters.

```
[...] = mle(data, 'nloglf', nloglf, 'start', start, ...)
```

returns MLEs for the parameters of the distribution whose negative log-likelihood is given by `nloglf`. `nloglf` is a function handle, specified using the @ sign, that accepts the four input arguments:

- `params` - a vector of distribution parameter values
- `data` - a vector of data
- `cens` - a Boolean vector of censoring values
- `freq` - a vector of integer data frequencies

`nloglf` must accept all four arguments even if you do not supply the 'censoring' or 'frequency' name/value pairs (see above). However, `nloglf` can safely ignore its `cens` and `freq` arguments in that case. `nloglf` returns a scalar negative log-likelihood value and, optionally, a negative log-likelihood gradient vector (see the 'GradObj' statset parameter below). `start` is a vector containing initial values for the distribution's parameters.

`pdf`, `cdf`, `logpdf`, `logsf`, or `nloglf` can also be cell arrays whose first element is a function handle as defined above, and whose remaining elements are additional arguments to the function. `mle` places these arguments at the end of the argument list in the function call.

The following optional argument name/value pairs are valid only when 'pdf' and 'cdf', 'logpdf' and 'logcdf', or 'nloglf' are given:

- 'lowerbound' — A vector the same size as `start` containing lower bounds for the distribution parameters. The default is `-Inf`.
- 'upperbound' — A vector the same size as `start` containing upper bounds for the distribution parameters. The default is `Inf`.
- 'optimfun' — A string, either 'fminsearch' or 'fmincon', naming the optimization function to be used in maximizing the likelihood.

The default is 'fminsearch'. You can only specify 'fmincon' if Optimization Toolbox software is available.

When fitting a custom distribution, use the 'options' parameter to control details of the maximum likelihood optimization. See `statset('mlecustom')` for parameter names and default values. `mle` interprets the following `statset` parameters for custom distribution fitting as follows:

Parameter	Value
'GradObj'	'on' or 'off', indicating whether or not <code>fmincon</code> can expect the function provided with the 'nloglf' name/value pair to return the gradient vector of the negative log-likelihood as a second output. The default is 'off'. Ignored when using <code>fminsearch</code> .
'DerivStep'	The relative difference used in finite difference derivative approximations when using <code>fmincon</code> , and 'GradObj' is 'off'. 'DerivStep' can be a scalar, or the same size as 'start'. The default is $\text{eps}^{(1/3)}$. Ignored when using <code>fminsearch</code> .
'FunValCheck'	'on' or 'off', indicating whether or not <code>mle</code> should check the values returned by the custom distribution functions for validity. The default is 'on'. A poor choice of starting point can sometimes cause these functions to return NaNs, infinite values, or out of range values if they are written without suitable error-checking.
'TolBnd'	An offset for upper and lower bounds when using <code>fmincon</code> . <code>mle</code> treats upper and lower bounds as strict inequalities (i.e., open bounds). With <code>fmincon</code> , this is approximated by creating closed bounds inset from the specified upper and lower bounds by <code>TolBnd</code> . The default is $1\text{e-}6$.

Examples

The following returns an MLE and a 95% confidence interval for the success probability of a binomial distribution with 20 trials:

```
data = binornd(20,0.75,100,1); % Simulated data, p = 0.75

[phat,pci] = mle(data,'distribution','binomial',...
                 'alpha',.05,'ntrials',20)

phat =
    0.7370
pci =
    0.7171
    0.7562
```

See Also

betafit | binofit | evfit | expfit | gamfit | gevfit | gpdfit
| lognfit | nbinfit | normfit | mlecov | poissfit | raylfit |
statset | unifit | wblfit

Purpose Asymptotic covariance of maximum likelihood estimators

Syntax

```
ACOV = mlecov(params,data,...)
ACOV = mlecov(params,data,'pdf',pdf,'cdf',cdf)
ACOV = mlecov(params,data,'logpdf',logpdf,'logsf',logsf)
ACOV = mlecov(params,data,'nloglf',nloglf)
[...] = mlecov(params,data,...,param1,val1,param2,val2,...)
```

Description `ACOV = mlecov(params,data,...)` returns an approximation to the asymptotic covariance matrix of the maximum likelihood estimators of the parameters for a specified distribution. The following paragraphs describe how to specify the distribution. `mlecov` computes a finite difference approximation to the Hessian of the log-likelihood at the maximum likelihood estimates `params`, given the observed data, and returns the negative inverse of that Hessian. `ACOV` is a p -by- p matrix, where p is the number of elements in `params`.

You must specify a distribution after the input argument `data`, as follows.

`ACOV = mlecov(params,data,'pdf',pdf,'cdf',cdf)` enables you to define a distribution by its probability density and cumulative distribution functions, `pdf` and `cdf`, respectively. `pdf` and `cdf` are function handles that you create using the `@` sign. They accept a vector of data and one or more individual distribution parameters as inputs and return vectors of probability density function values and cumulative distribution values, respectively. If the `'censoring'` name/value pair (see below) is not present, you can omit the `'cdf'` name/value pair.

`ACOV = mlecov(params,data,'logpdf',logpdf,'logsf',logsf)` enables you to define a distribution by its log probability density and log survival functions, `logpdf` and `logsf`, respectively. `logpdf` and `logsf` are function handles that you create using the `@` sign. They accept as inputs a vector of data and one or more individual distribution parameters, and return vectors of logged probability density values and logged survival function values, respectively. If the `'censoring'` name/value pair (see below) is not present, you can omit the `'logsf'` name/value pair.

`ACOV = mlecov(params,data,'nloglf',nloglf)` enables you to define a distribution by its log-likelihood function. `nloglf` is a function handle, specified using the `@` sign, that accepts the following four input arguments:

- `params` — Vector of distribution parameter values
- `data` — Vector of data
- `cens` — Boolean vector of censoring values
- `freq` — Vector of integer data frequencies

`nloglf` must accept all four arguments even if you do not supply the 'censoring' or 'frequency' name/value pairs (see below). However, `nloglf` can safely ignore its `cens` and `freq` arguments in that case. `nloglf` returns a scalar negative log-likelihood value and, optionally, the negative log-likelihood gradient vector (see the 'gradient' name/value pair below).

`pdf`, `cdf`, `logpdf`, `logsf`, and `nloglf` can also be cell arrays whose first element is a function handle, as defined above, and whose remaining elements are additional arguments to the function. The `mle` function places these arguments at the end of the argument list in the function call.

`[...] = mlecov(params,data,...,param1,val1,param2,val2,...)` specifies optional parameter name/value pairs chosen from the following table.

Parameter	Value
'censoring'	Boolean vector of the same size as <code>data</code> , containing 1's when the corresponding elements of <code>data</code> are right-censored observations and 0's when the corresponding elements are exact observations. The default is that all observations are observed exactly. Censoring is not supported for all distributions.
'frequency'	A vector of the same size as <code>data</code> containing nonnegative frequencies for the corresponding elements in <code>data</code> . The default is one observation per element of <code>data</code> .
'options'	A structure <code>opts</code> containing numerical options for the finite difference Hessian calculation. You create <code>opts</code> by calling <code>statset</code> . The applicable <code>statset</code> parameters are: <ul style="list-style-type: none"> 'GradObj' — 'on' or 'off', indicating whether or not the function provided with the 'nloglf' name/value pair can return the gradient vector of the negative log-likelihood as its second output. The default is 'off'. 'DerivStep' — Relative step size used in finite difference for Hessian calculations. Can be a scalar, or the same size as <code>params</code>. The default is $\text{eps}^{(1/4)}$. A smaller value might be appropriate if 'GradObj' is 'on'.

Examples

Create the following function:

```
function logpdf = betalogpdf(x,a,b)
logpdf = (a-1)*log(x)+(b-1)*log(1-x)-betaln(a,b);
```

Fit a beta distribution to some simulated data, and compute the approximate covariance matrix of the parameter estimates:


```
x = betarnd(1.23,3.45,25,1);  
phat = mle(x,'dist','beta')  
acov = mlecov(phat,x,'logpdf',@betalogpdf)
```

See Also

mle

Purpose Multinomial probability density function

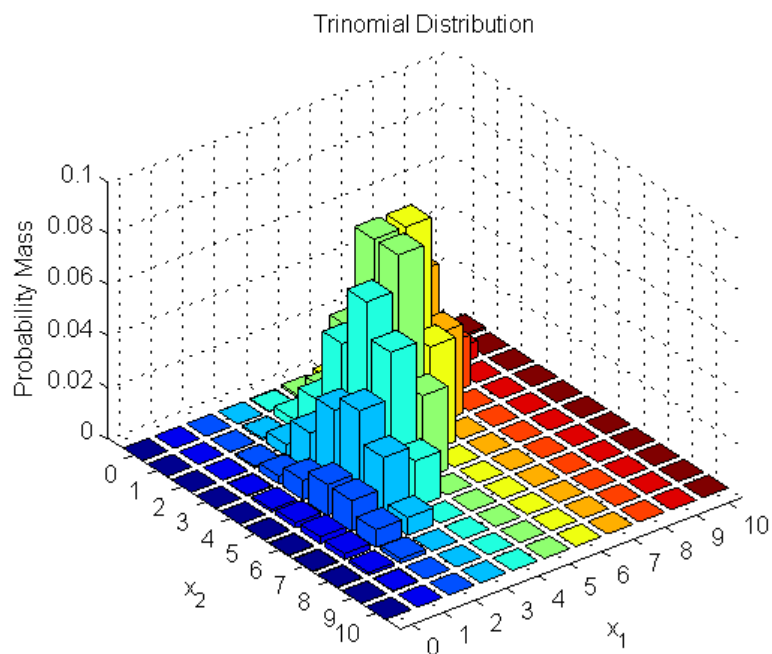
Syntax `Y = mnpdf(X,PROB)`

Description `Y = mnpdf(X,PROB)` returns the pdf for the multinomial distribution with probabilities `PROB`, evaluated at each row of `X`. `X` and `PROB` are m -by- k matrices or 1-by- k vectors, where k is the number of multinomial bins or categories. Each row of `PROB` must sum to one, and the sample sizes for each observation (rows of `X`) are given by the row sums `sum(X,2)`. `Y` is an m -by- k matrix, and `mnpdf` computes each row of `Y` using the corresponding rows of the inputs, or replicates them if needed.

Examples

```
% Compute the distribution
p = [1/2 1/3 1/6]; % Outcome probabilities
n = 10; % Sample size
x1 = 0:n;
x2 = 0:n;
[X1,X2] = meshgrid(x1,x2);
X3 = n-(X1+X2);
Y = mnpdf([X1(:),X2(:),X3(:)],repmat(p,(n+1)^2,1));

% Plot the distribution
Y = reshape(Y,n+1,n+1);
bar3(Y)
set(gca,'XTickLabel',0:n)
set(gca,'YTickLabel',0:n)
xlabel('x_1')
ylabel('x_2')
zlabel('Probability Mass')
title('Trinomial Distribution')
```



Note that the visualization does not show x_3 , which is determined by the constraint $x_1 + x_2 + x_3 = n$.

See Also

`mnrnd`

How To

- “Multinomial Distribution” on page B-67

Purpose Multinomial logistic regression

Syntax

```
B = mnrfi(X,Y)
B = mnrfi(X,Y,param1,va11,param2,va12,...)
[B,dev] = mnrfi(...)
[B,dev,stats] = mnrfi(...)
```

Description `B = mnrfi(X,Y)` returns a matrix `B` of coefficient estimates for a multinomial logistic regression of the responses in `Y` on the predictors in `X`. `X` is an n -by- p matrix of p predictors at each of n observations. `Y` is an n -by- k matrix, where `Y(i,j)` is the number of outcomes of the multinomial category `j` for the predictor combinations given by `X(i,:)`. The sample sizes for each observation are given by the row sums `sum(Y,2)`.

Alternatively, `Y` can be an n -by-1 column vector of scalar integers from 1 to k indicating the value of the response for each observation, and all sample sizes are taken to be 1.

The result `B` is a $(p+1)$ -by- $(k-1)$ matrix of estimates, where each column corresponds to the estimated intercept term and predictor coefficients, one for each of the first $k-1$ multinomial categories. The estimates for the k^{th} category are taken to be zero.

Note `mnrfi` automatically includes a constant term in all models. Do not enter a column of 1s directly into `X`.

`mnrfi` treats NaNs in either `X` or `Y` as missing values, and ignores them.

`B = mnrfi(X,Y,param1,va11,param2,va12,...)` allows you to specify optional parameter name/value pairs to control the model fit. Parameters are:

- `'model'` — The type of model to fit; one of the text strings `'nominal'` (the default), `'ordinal'`, or `'hierarchical'`

- 'interactions' — Determines whether the model includes an interaction between the multinomial categories and the coefficients. Specify as 'off' to fit a model with a common set of coefficients for the predictor variables, across all multinomial categories. This is often described as *parallel regression*. Specify as 'on' to fit a model with different coefficients across categories. In all cases, the model has different intercepts across categories. Thus, B is a vector containing $k-1+p$ coefficient estimates when 'interaction' is 'off', and a $(p+1)$ -by- $(k-1)$ matrix when it is 'on'. The default is 'off' for ordinal models, and 'on' for nominal and hierarchical models.
- 'link' — The link function to use for ordinal and hierarchical models. The link function defines the relationship $g(\mu_{ij}) = x_i b_j$ between the mean response for the i^{th} observation in the j^{th} category, μ_{ij} , and the linear combination of predictors $x_i b_j$. Specify the link parameter value as one of the text strings 'logit' (the default), 'probit', 'comloglog', or 'loglog'. You may not specify the 'link' parameter for nominal models; these always use a multivariate logistic link.
- 'estdisp' — Specify as 'on' to estimate a dispersion parameter for the multinomial distribution in computing standard errors, or 'off' (the default) to use the theoretical dispersion value of 1.

[B,dev] = mnrfit(...) returns the deviance of the fit dev.

[B,dev,stats] = mnrfit(...) returns a structure stats that contains the following fields:

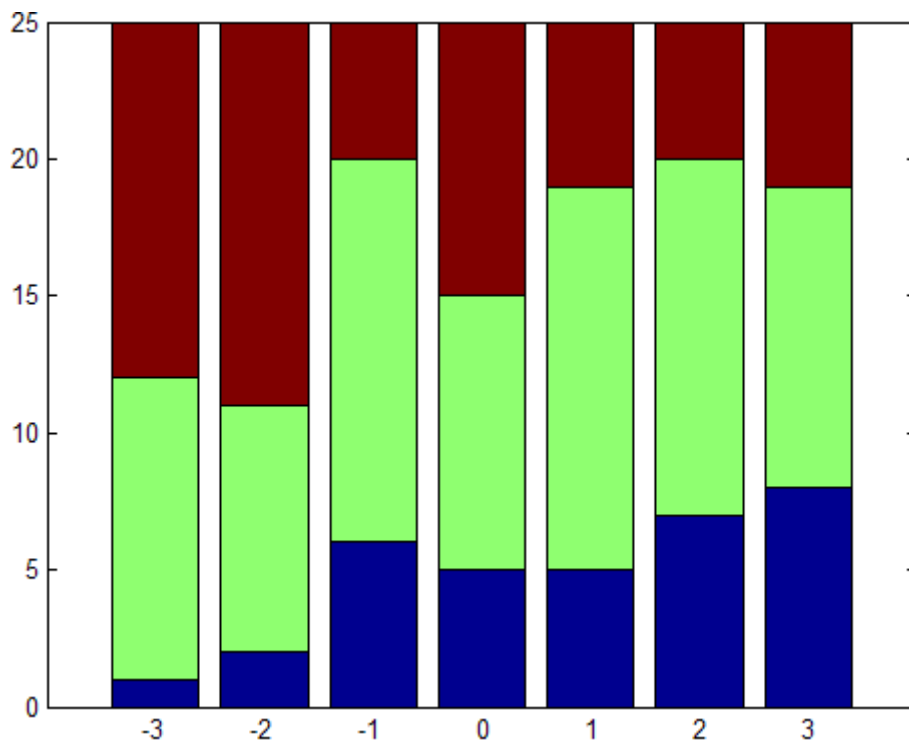
- dfe — Degrees of freedom for error
- s — Theoretical or estimated dispersion parameter
- sfit — Estimated dispersion parameter
- se — Standard errors of coefficient estimates B
- coeffcorr — Estimated correlation matrix for B
- covb — Estimated covariance matrix for B

- t — t statistics for B
- p — p -values for B
- resid — Residuals
- residp — Pearson residuals
- residd — Deviance residuals

Examples

Fit multinomial logistic regression models to data with one predictor variable and three categories in the response variable:

```
x = [-3 -2 -1 0 1 2 3]';  
Y = [1 11 13; 2 9 14; 6 14 5; 5 10 10; 5 14 6; 7 13 5; ...  
     8 11 6];  
bar(x,Y,'stacked'); ylim([0 25]);
```



```
% Now fit a nominal model for the individual response
% category probabilities, with separate slopes on the
% single predictor variable, x, for each
% category:
```

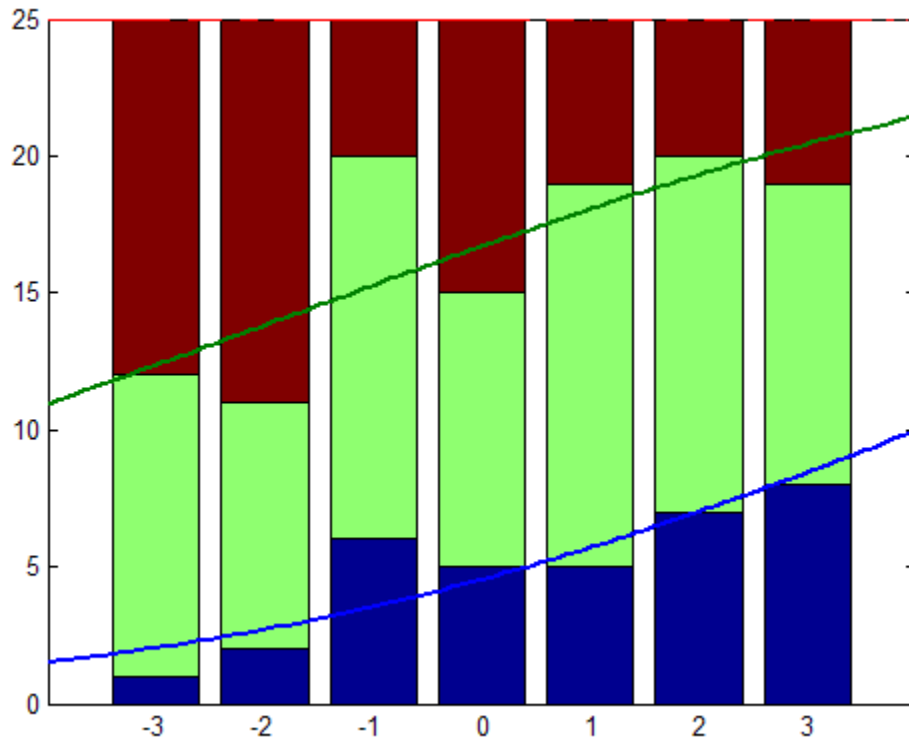
```
% The first row of betaHatNom contains the intercept terms
% for the first two response categories. The second row
% contains the slopes.
```

```
betaHatNom = mnrfit(x,Y,'model','nominal',...
'interactions','on')
```

```
% Compute the predicted probabilities for the three
```

mnrfit

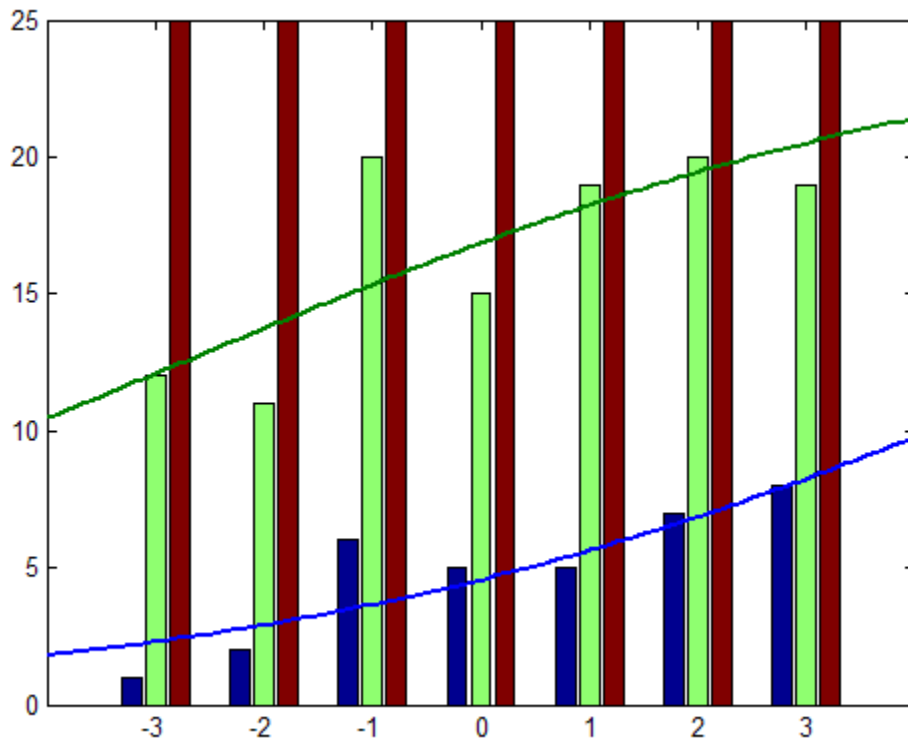
```
% response categories:  
xx = linspace(-4,4)';  
pHatNom = mnrfval(betaHatNom,xx,'model','nominal',...  
  'interactions','on');  
line(xx,cumsum(25*pHatNom,2),'LineWidth',2);
```



Fit a "parallel" ordinal model for the cumulative response category probabilities, with a common slope on the single predictor variable, x , across all categories:

```
% The first two elements of betaHatOrd are the
% intercept terms for the first two response categories.
% The last element of betaHatOrd is the common slope.
betaHatOrd = mnrfits(x,Y,'model','ordinal',...
    'interactions','off')

% Compute the predicted cumulative probabilities for the
% first two response categories. The cumulative
% probability for the third category is always 1.
pHatOrd = mnrfits(betaHatOrd,xx,'type','cumulative',...
    'model','ordinal','interactions','off');
bar(x,cumsum(Y,2),'grouped'); ylim([0 25]);
line(xx,25*pHatOrd,'LineWidth',2);
```



References

[1] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*. New York: Chapman & Hall, 1990.

See Also

`mnrval` | `glmfit` | `glmval` | `regress` | `regstats`

How To

- “Multinomial Distribution” on page B-67

Purpose Multinomial random numbers

Syntax

```
r = mnrnd(n,p)
R = mnrnd(n,p,m)
R = mnrnd(N,P)
```

Description `r = mnrnd(n,p)` returns random values `r` from the multinomial distribution with parameters `n` and `p`. `n` is a positive integer specifying the number of trials (sample size) for each multinomial outcome. `p` is a 1-by-`k` vector of multinomial probabilities, where `k` is the number of multinomial bins or categories. `p` must sum to one. (If `p` does not sum to one, `r` consists entirely of NaN values.) `r` is a 1-by-`k` vector, containing counts for each of the `k` multinomial bins.

`R = mnrnd(n,p,m)` returns `m` random vectors from the multinomial distribution with parameters `n` and `p`. `R` is a `m`-by-`k` matrix, where `k` is the number of multinomial bins or categories. Each row of `R` corresponds to one multinomial outcome.

`R = mnrnd(N,P)` generates outcomes from different multinomial distributions. `P` is a `m`-by-`k` matrix, where `k` is the number of multinomial bins or categories and each of the `m` rows contains a different set of multinomial probabilities. Each row of `P` must sum to one. (If any row of `P` does not sum to one, the corresponding row of `R` consists entirely of NaN values.) `N` is a `m`-by-1 vector of positive integers or a single positive integer (replicated by `mnrnd` to a `m`-by-1 vector). `R` is a `m`-by-`k` matrix. Each row of `R` is generated using the corresponding rows of `N` and `P`.

Examples Generate 2 random vectors with the same probabilities:

```
n = 1e3;
p = [0.2,0.3,0.5];
R = mnrnd(n,p,2)
R =
    215    282    503
    194    303    503
```

mnrnd

Generate 2 random vectors with different probabilities:

```
n = 1e3;  
P = [0.2, 0.3, 0.5; ...  
     0.3, 0.4, 0.3;];  
R = mnrnd(n,P)  
R =  
    186    290    524  
    290    389    321
```

See Also

mnpdf

How To

- “Multinomial Distribution” on page B-67

Purpose Multinomial logistic regression values

Syntax

```
PHAT = mnrvl(B,X)
YHAT = mnrvl(B,X,ssize)
[... ,DLO,DHI] = mnrvl(B,X,... ,stats)
[... ] = mnrvl(... ,param1,va11,param2,va12,... )
```

Description PHAT = mnrvl(B,X) computes predicted probabilities for the multinomial logistic regression model with predictors X. B contains intercept and coefficient estimates as returned by the mnrfi function. X is an *n*-by-*p* matrix of *p* predictors at each of *n* observations. PHAT is an *n*-by-*k* matrix of predicted probabilities for each multinomial category.

Note mnrvl automatically includes a constant term in all models. Do not enter a column of 1s directly into X.

YHAT = mnrvl(B,X,ssize) computes predicted category counts for sample sizes ssize. ssize is an *n*-by-1 column vector of positive integers.

[... ,DLO,DHI] = mnrvl(B,X,... ,stats) also computes 95% confidence bounds on the predicted probabilities PHAT or counts YHAT. stats is the structure returned by the mnrfi function. DLO and DHI define a lower confidence bound of PHAT or YHAT minus DLO and an upper confidence bound of PHAT or YHAT plus DHI. Confidence bounds are nonsimultaneous and they apply to the fitted curve, not to new observations.

[...] = mnrvl(... ,param1,va11,param2,va12,...) allows you to specify optional parameter name/value pairs to control the predicted values. These parameters must be set to the corresponding values used with the mnrfi function to compute B. Parameters are:

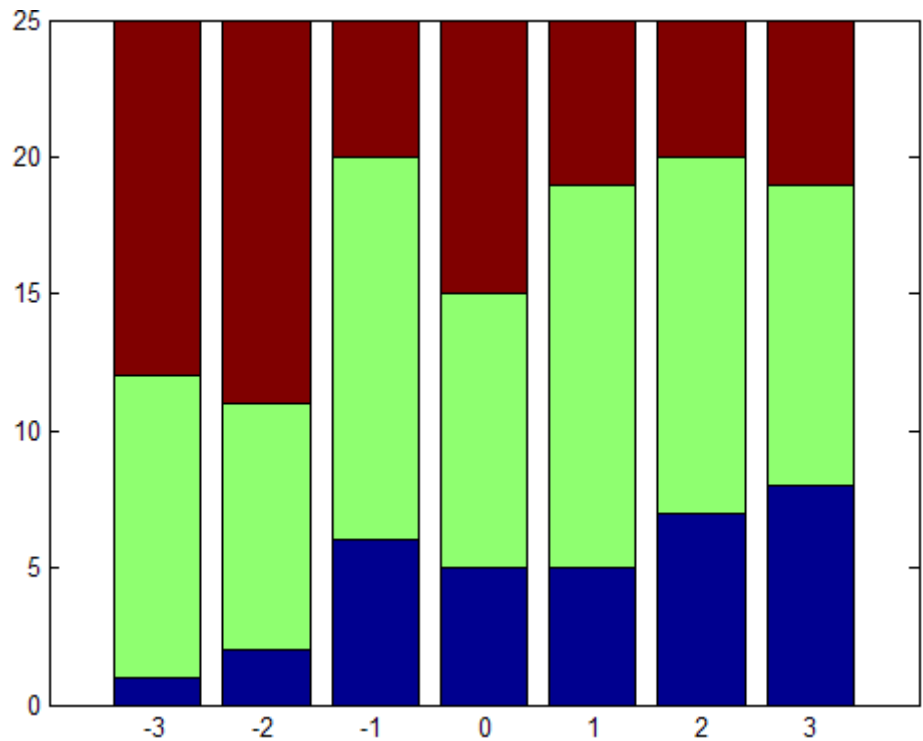
- 'model' — The type of model that was fit by mnrfi; one of the text strings 'nominal' (the default), 'ordinal', or 'hierarchical'.

- 'interactions' — Determines whether the model fit by `mnrfit` included an interaction between the multinomial categories and the coefficients. The default is 'off' for ordinal models, and 'on' for nominal and hierarchical models.
- 'link' — The link function that was used by `mnrfit` for ordinal and hierarchical models. Specify the link parameter value as one of the text strings 'logit' (the default), 'probit', 'comploglog', or 'loglog'. You may not specify the 'link' parameter for nominal models; these always use a multivariate logistic link.
- 'type' — Set to 'category' (the default) to return predictions and confidence bounds for the probabilities (or counts) of the k multinomial categories. Set to 'cumulative' to return predictions and confidence bounds for the cumulative probabilities (or counts) of the first $k-1$ multinomial categories, as an n -by- $(k-1)$ matrix. The predicted cumulative probability for the k th category is 1. Set to 'conditional' to return predictions and confidence bounds in terms of the first $k-1$ conditional category probabilities, i.e., the probability for category j , given an outcome in category j or higher. When 'type' is 'conditional', and you supply the sample size argument `ssize`, the predicted counts at each row of X are conditioned on the corresponding element of `ssize`, across all categories.
- 'confidence' — The confidence level for the confidence bounds; a value between 0 and 1. The default is 0.95.

Examples

Fit multinomial logistic regression models to data with one predictor variable and three categories in the response variable:

```
x = [-3 -2 -1 0 1 2 3]';  
Y = [1 11 13; 2 9 14; 6 14 5; 5 10 10; 5 14 6; 7 13 5; ...  
     8 11 6];  
bar(x,Y,'stacked');  
ylim([0 25]);
```



```
% Now fit a nominal model for the individual response
% category probabilities, with separate slopes on the
% single predictor variable, x, for each
% category:
```

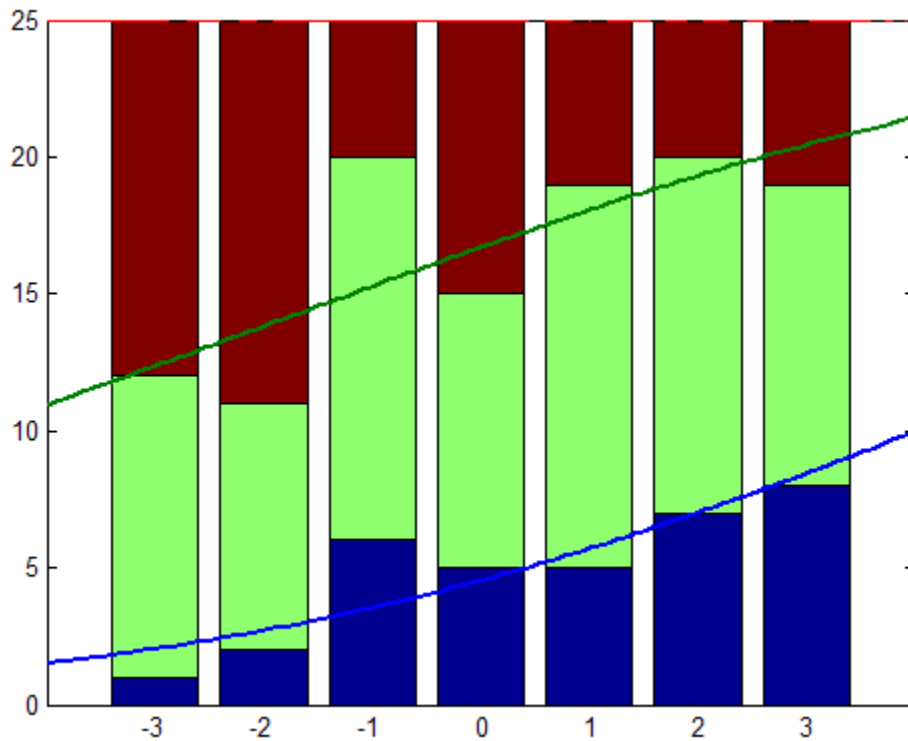
```
% The first row of betaHatNom contains the intercept terms
% for the first two response categories. The second row
% contains the slopes.
```

```
betaHatNom = mnrfits(x,Y,'model','nominal',...
    'interactions','on')
```

```
% Compute the predicted probabilities for the three
% response categories:
```

mnrval

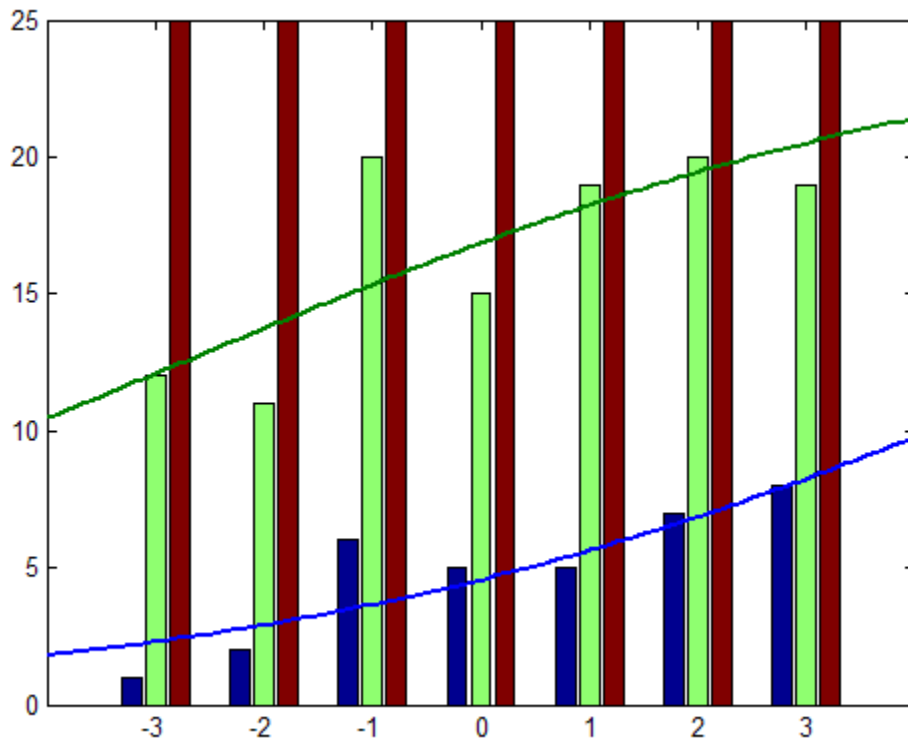
```
xx = linspace(-4,4)';  
pHatNom = mnrvl(betaHatNom,xx,'model','nominal',...  
    'interactions','on');  
line(xx,cumsum(25*pHatNom,2),'LineWidth',2);
```



Fit a "parallel" ordinal model for the cumulative response category probabilities, with a common slope on the single predictor variable, x , across all categories:


```
% The first two elements of betaHatOrd are the
% intercept terms for the first two response categories.
% The last element of betaHatOrd is the common slope.
betaHatOrd = mnrfits(x,Y,'model','ordinal',...
    'interactions','off')

% Compute the predicted cumulative probabilities for the
% first two response categories. The cumulative
% probability for the third category is always 1.
pHatOrd = mnrfits(betaHatOrd,xx,'type','cumulative',...
    'model','ordinal','interactions','off');
bar(x,cumsum(Y,2),'grouped');
ylim([0 25]);
line(xx,25*pHatOrd,'LineWidth',2);
```



References

[1] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*. New York: Chapman & Hall, 1990.

See Also

[mnrfit](#) | [glmfit](#) | [glmval](#)

How To

- “Multinomial Distribution” on page B-67

Purpose

Central moments

Syntax

```
m = moment(X,order)
moment(X,order,dim)
```

Description

`m = moment(X,order)` returns the central sample moment of X specified by the positive integer order. For vectors, `moment(x,order)` returns the central moment of the specified order for the elements of x . For matrices, `moment(X,order)` returns central moment of the specified order for each column. For N-dimensional arrays, `moment` operates along the first nonsingleton dimension of X .

`moment(X,order,dim)` takes the moment along dimension `dim` of X .

Tips

Note that the central first moment is zero, and the second central moment is the variance computed using a divisor of n rather than $n - 1$, where n is the length of the vector x or the number of rows in the matrix X .

The central moment of order k of a distribution is defined as

$$m_k = E(x - \mu)^k$$

where $E(x)$ is the expected value of x .

Examples

```
X = randn([6 5])
X =
    1.1650    0.0591    1.2460   -1.2704   -0.0562
    0.6268    1.7971   -0.6390    0.9846    0.5135
    0.0751    0.2641    0.5774   -0.0449    0.3967
    0.3516    0.8717   -0.3600   -0.7989    0.7562
   -0.6965   -1.4462   -0.1356   -0.7652    0.4005
    1.6961   -0.7012   -1.3493    0.8617   -1.3414

m = moment(X,3)
m =
   -0.0282    0.0571    0.1253    0.1460   -0.4486
```

moment

See Also

kurtosis | mean | skewness | std | var

Purpose Input matrix of means MU

Description Input matrix of means mu.

multcompare

Purpose Multiple comparison test

Syntax

```
c = multcompare(stats)
c = multcompare(stats,param1,val1,param2,val2,...)
[c,m] = multcompare(...)
[c,m,h] = multcompare(...)
[c,m,h,gnames] = multcompare(...)
```

Description `c = multcompare(stats)` performs a multiple comparison test using the information in the `stats` structure, and returns a matrix `c` of pairwise comparison results. It also displays an interactive graph of the estimates with comparison intervals around them. See “Examples” on page 20-1353.

In a one-way analysis of variance, you compare the means of several groups to test the hypothesis that they are all the same, against the general alternative that they are not all the same. Sometimes this alternative may be too general. You may need information about which pairs of means are significantly different, and which are not. A test that can provide such information is called a *multiple comparison procedure*.

When you perform a simple t-test of one group mean against another, you specify a significance level that determines the cutoff value of the t statistic. For example, you can specify the value `alpha = 0.05` to insure that when there is no real difference, you will incorrectly find a significant difference no more than 5% of the time. When there are many group means, there are also many pairs to compare. If you applied an ordinary t-test in this situation, the `alpha` value would apply to each comparison, so the chance of incorrectly finding a significant difference would increase with the number of comparisons. Multiple comparison procedures are designed to provide an upper bound on the probability that *any* comparison will be incorrectly found significant.

The output `c` contains the results of the test in the form of a five-column matrix. Each row of the matrix represents one test, and there is one row for each pair of groups. The entries in the row indicate the means being compared, the estimated difference in means, and a confidence interval for the difference.

For example, suppose one row contains the following entries.

2.0000 5.0000 1.9442 8.2206 14.4971

These numbers indicate that the mean of group 2 minus the mean of group 5 is estimated to be 8.2206, and a 95% confidence interval for the true difference of the means is [1.9442, 14.4971].

In this example the confidence interval does not contain 0.0, so the difference is significant at the 0.05 level. If the confidence interval did contain 0.0, the difference would not be significant at the 0.05 level.

The `multcompare` function also displays a graph with each group mean represented by a symbol and an interval around the symbol. Two means are significantly different if their intervals are disjoint, and are not significantly different if their intervals overlap. You can use the mouse to select any group, and the graph will highlight any other groups that are significantly different from it.

`c = multcompare(stats,param1,va11,param2,va12,...)` specifies one or more of the parameter name/value pairs described in the following table.

Parameter	Values
'alpha'	Scalar between 0 and 1 that determines the confidence levels of the intervals in the matrix <code>c</code> and in the figure (default is 0.05). The confidence level is $100(1 - \alpha)\%$.
'display'	Either 'on' (the default) to display a graph of the estimates with comparison intervals around them, or 'off' to omit the graph. See “Examples” on page 20-1353.
'ctype'	Specifies the type of critical value to use for the multiple comparison. “Values of <code>ctype</code> ” on page 20-1351 describes the allowed values for <code>ctype</code> .

multcompare

Parameter	Values
'dimension'	A vector specifying the dimension or dimensions over which the population marginal means are to be calculated. Use only if you create stats with the function <code>anovan</code> . The default is 1 to compute over the first dimension. See “Dimension Parameter” on page 20-1353 for more information.
'estimate'	Specifies the estimate to be compared. The allowable values of estimate depend on the function that was the source of the stats structure, as described in “Values of estimate” on page 20-1352

`[c,m] = multcompare(...)` returns an additional matrix `m`. The first column of `m` contains the estimated values of the means (or whatever statistics are being compared) for each group, and the second column contains their standard errors.

`[c,m,h] = multcompare(...)` returns a handle `h` to the comparison graph. Note that the title of this graph contains instructions for interacting with the graph, and the *x*-axis label contains information about which means are significantly different from the selected mean. If you plan to use this graph for presentation, you may want to omit the title and the *x*-axis label. You can remove them using interactive features of the graph window, or you can use the following commands.

```
title('')  
xlabel('')
```

`[c,m,h,gnames] = multcompare(...)` returns `gnames`, a cell array with one row for each group, containing the names of the groups.

The intervals shown in the graph are computed so that to a very close approximation, two estimates being compared are significantly different if their intervals are disjoint, and are not significantly different if their intervals overlap. (This is exact for multiple comparison of means from

anova1, if all means are based on the same sample size.) You can click on any estimate to see which means are significantly different from it.

Values of ctype

The following table describes the allowed values for the parameter ctype.

Value	Description
'hsd' or 'tukey-kramer'	Use Tukey's honestly significant difference criterion. This is the default, and it is based on the Studentized range distribution. It is optimal for balanced one-way ANOVA and similar procedures with equal sample sizes. It has been proven to be conservative for one-way ANOVA with different sample sizes. According to the unproven Tukey-Kramer conjecture, it is also accurate for problems where the quantities being compared are correlated, as in analysis of covariance with unbalanced covariate values.
'lsd'	Use Tukey's least significant difference procedure. This procedure is a simple t-test. It is reasonable if the preliminary test (say, the one-way ANOVA <i>F</i> statistic) shows a significant difference. If it is used unconditionally, it provides no protection against multiple comparisons.
'bonferroni'	Use critical values from the t distribution, after a Bonferroni adjustment to compensate for multiple comparisons. This procedure is conservative, but usually less so than the Scheffé procedure.

multcompare

Value	Description
'dunn-sidak'	Use critical values from the t distribution, after an adjustment for multiple comparisons that was proposed by Dunn and proved accurate by Sidák. This procedure is similar to, but less conservative than, the Bonferroni procedure.
'scheffe'	Use critical values from Scheffé's S procedure, derived from the F distribution. This procedure provides a simultaneous confidence level for comparisons of all linear combinations of the means, and it is conservative for comparisons of simple differences of pairs.

Values of estimate

The allowable values of the parameter 'estimate' depend on the function that was the source of the stats structure, according to the following table.

Source	Values
'anova1'	Ignored. Always compare the group means.
'anova2'	Either 'column' (the default) or 'row' to compare column or row means.
'anovan'	Ignored. Always compare the population marginal means as specified by the dim argument.
'aoctool'	Either 'slope', 'intercept', or 'pmm' to compare slopes, intercepts, or population marginal means. If the analysis of covariance model did not include separate slopes, then 'slope' is not allowed. If it did not include separate intercepts, then no comparisons are possible.

Source	Values
'friedman'	Ignored. Always compare average column ranks.
'kruskalwallis'	Ignored. Always compare average group ranks.

Dimension Parameter

The dimension parameter is a vector specifying the dimension or dimensions over which the population marginal means are to be calculated. For example, if `dim = 1`, the estimates that are compared are the means for each value of the first grouping variable, adjusted by removing effects of the other grouping variables as if the design were balanced. If `dim = [1 3]`, population marginal means are computed for each combination of the first and third grouping variables, removing effects of the second grouping variable. If you fit a singular model, some cell means may not be estimable and any population marginal means that depend on those cell means will have the value `NaN`.

Population marginal means are described by Milliken and Johnson (1992) and by Searle, Speed, and Milliken (1980). The idea behind population marginal means is to remove any effect of an unbalanced design by fixing the values of the factors specified by `dim`, and averaging out the effects of other factors as if each factor combination occurred the same number of times. The definition of population marginal means does not depend on the number of observations at each factor combination. For designed experiments where the number of observations at each factor combination has no meaning, population marginal means can be easier to interpret than simple means ignoring other factors. For surveys and other studies where the number of observations at each combination does have meaning, population marginal means may be harder to interpret.

Examples

Example 1

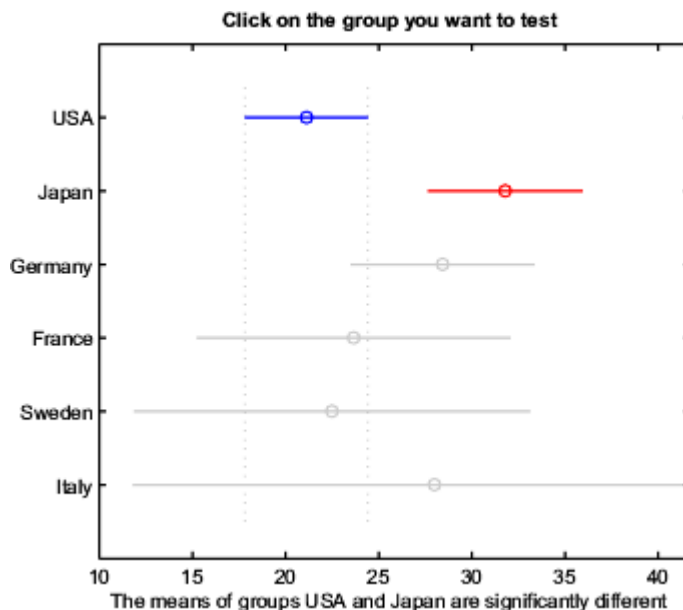
The following example performs a 1-way analysis of variance (ANOVA) and displays group means with their names.

```
load carsmall
```

multcompare

```
[p,t,st] = anova1(MPG,Origin,'off');  
[c,m,h,nms] = multcompare(st,'display','off');  
[nms num2cell(m)]  
ans =  
  'USA'      [21.1328]  [0.8814]  
  'Japan'    [31.8000]  [1.8206]  
  'Germany'  [28.4444]  [2.3504]  
  'France'   [23.6667]  [4.0711]  
  'Sweden'   [22.5000]  [4.9860]  
  'Italy'    [28.0000]  [7.0513]
```

multcompare also displays the following graph of the estimates with comparison intervals around them.



You can click the graphs of each country to compare its mean to those of other countries.

Example 2

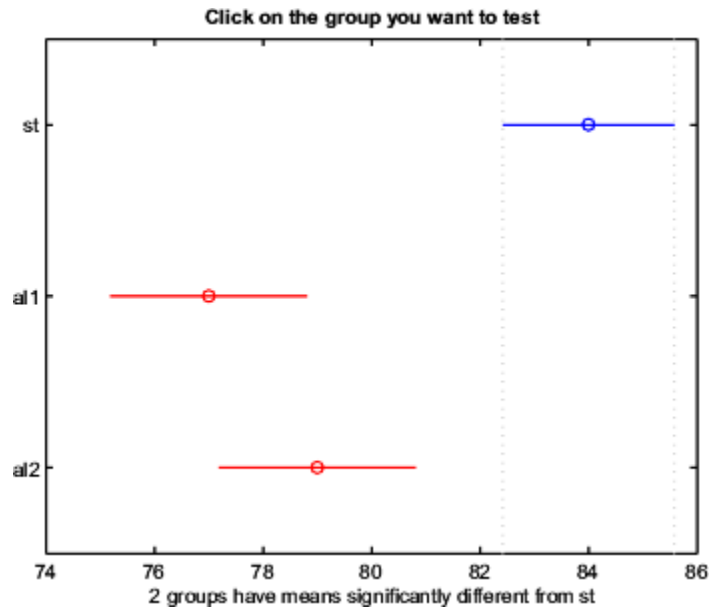
The following continues the example described in the `anova1` reference page, which is related to testing the material strength in structural beams. From the `anova1` output you found significant evidence that the three types of beams are not equivalent in strength. Now you can determine where those differences lie. First you create the data arrays and you perform one-way ANOVA.

```
strength = [82 86 79 83 84 85 86 87 74 82 ...
            78 75 76 77 79 79 77 78 82 79];
alloy = {'st','st','st','st','st','st','st','st',...
        'a11','a11','a11','a11','a11','a11',...
        'a12','a12','a12','a12','a12','a12'};
[p,a,s] = anova1(strength,alloy);
```

Among the outputs is a structure that you can use as input to `multcompare`.

```
[c,m,h,nms] = multcompare(s);
[nms num2cell(c)]
ans =
    'st'    [1]    [2]    [ 3.6064]    [ 7]    [10.3936]
    'a11'   [1]    [3]    [ 1.6064]    [ 5]    [ 8.3936]
    'a12'   [2]    [3]    [-5.6280]   [-2]    [ 1.6280]
```

multcompare



The third row of the output matrix shows that the differences in strength between the two alloys is not significant. A 95% confidence interval for the difference is $[-5.6, 1.6]$, so you cannot reject the hypothesis that the true difference is zero.

The first two rows show that both comparisons involving the first group (steel) have confidence intervals that do not include zero. In other words, those differences are significant. The graph shows the same information.

References

- [1] Hochberg, Y., and A. C. Tamhane. *Multiple Comparison Procedures*. Hoboken, NJ: John Wiley & Sons, 1987.
- [2] Milliken, G. A., and D. E. Johnson. *Analysis of Messy Data, Volume 1: Designed Experiments*. Boca Raton, FL: Chapman & Hall/CRC Press, 1992.

[3] Searle, S. R., F. M. Speed, and G. A. Milliken. "Population marginal means in the linear model: an alternative to least-squares means." *American Statistician*. 1980, pp. 216–221.

See Also

`anova1` | `anova2` | `anovan` | `aoctool` | `friedman` | `kruskalwallis`

multivarichart

Purpose Multivari chart for grouped data

Syntax
`multivarichart(y, GROUP)`
`multivarichart(Y)`
`multivarichart(..., param1, val1, param2, val2, ...)`
`[charthandle, AXESH] = multivarichart(...)`

Description `multivarichart(y, GROUP)` displays the multivari chart for the vector `y` grouped by entries in the cell array `GROUP`. Each cell of `GROUP` must contain a grouping variable that can be a categorical variable, numeric vector, character matrix, or single-column cell array of strings. `GROUP` can also be a matrix whose columns represent different grouping variables. Each grouping variable must have the same number of elements as `y`. The number of grouping variables must be 2, 3, or 4.

Each subplot of the plot matrix contains a multivari chart for the first and second grouping variables. The *x*-axis in each subplot indicates values of the first grouping variable. The legend at the bottom of the figure window indicates values of the second grouping variable. The subplot at position (*i*, *j*) is the multivari chart for the subset of `y` at the *i*th level of the third grouping variable and the *j*th level of the fourth grouping variable. If the third or fourth grouping variable is absent, it is considered to have only one level.

`multivarichart(Y)` displays the multivari chart for a matrix `Y`. The data in different columns represent changes in one factor. The data in different rows represent changes in another factor.

`multivarichart(..., param1, val1, param2, val2, ...)` specifies one or more of the following name/value pairs:

- 'varnames' — Grouping variable names in a character matrix or a cell array of strings, one per grouping variable. Default names are 'X1', 'X2',
- 'plotorder' — A string with the value 'sorted' or a vector containing a permutation of the integers from 1 to the number of grouping variables.

If 'plotorder' is a string with value 'sorted', the grouping variables are rearranged in descending order according to the number of levels in each variable.

If 'plotorder' is a vector, it indicates the order in which each grouping variable should be plotted. For example, [2,3,1,4] indicates that the second grouping variable should be used as the x-axis of each subplot, the third grouping variable should be used as the legend, the first grouping variable should be used as the columns of the plot, and the fourth grouping variable should be used as the rows of the plot.

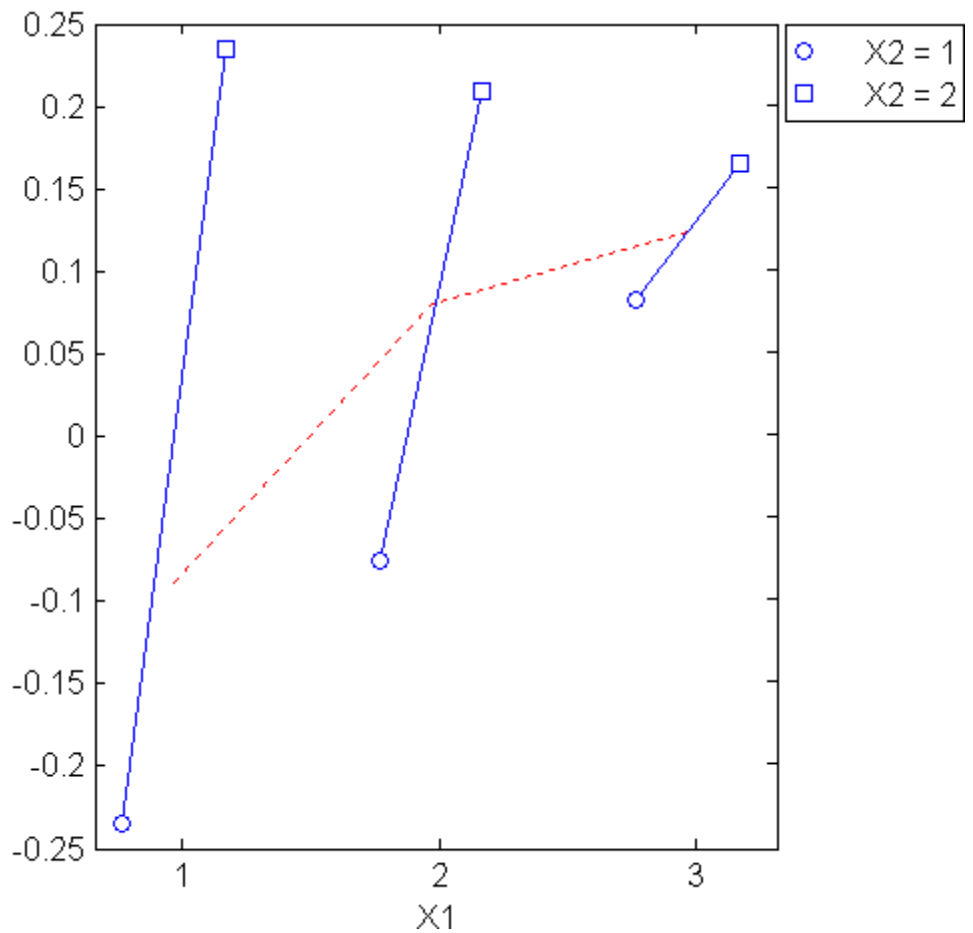
[charthandle,AXESH] = multivarichart(...) returns a handle charthandle to the figure window and a matrix AXESH of handles to the subplot axes.

Examples

Display a multivari chart for data with two grouping variables:

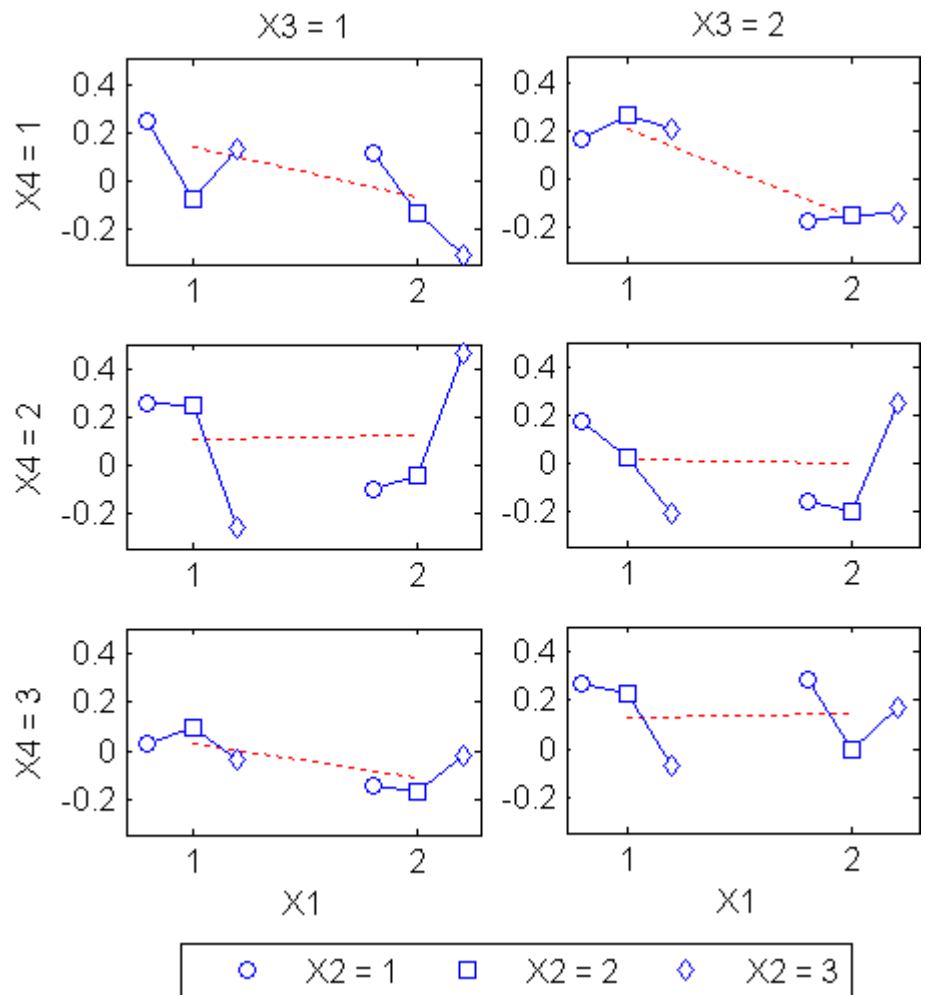
```
y = randn(100,1); % response
group = [ceil(3*rand(100,1)) ceil(2*rand(100,1))];
multivarichart(y,group)
```

multivarichart



Display a multivari chart for data with four grouping variables:

```
y = randn(1000,1); % response
group = {ceil(2*rand(1000,1)),ceil(3*rand(1000,1)), ...
        ceil(2*rand(1000,1)),ceil(3*rand(1000,1))};
multivarichart(y,group)
```



See Also

maineffectsplot | interactionplot

How To

- “Grouping Variables” on page 2-72

mvncdf

Purpose Multivariate normal cumulative distribution function

Syntax

```
y = mvncdf(X)
y = mvncdf(X,mu,SIGMA)
y = mvncdf(xl,xu,mu,SIGMA)
[y,err] = mvncdf(...)
[...] = mvncdf(...,options)
```

Description `y = mvncdf(X)` returns the cumulative probability of the multivariate normal distribution with zero mean and identity covariance matrix, evaluated at each row of X . Rows of the n -by- d matrix X correspond to observations or points, and columns correspond to variables or coordinates. y is an n -by-1 vector.

`y = mvncdf(X,mu,SIGMA)` returns the cumulative probability of the multivariate normal distribution with mean μ and covariance SIGMA , evaluated at each row of X . μ is a 1-by- d vector, and SIGMA is a d -by- d symmetric, positive definite matrix. μ can also be a scalar value, which `mvncdf` replicates to match the size of X . If the covariance matrix is diagonal, containing variances along the diagonal and zero covariances off the diagonal, SIGMA may also be specified as a 1-by- d vector containing just the diagonal. Pass in the empty matrix `[]` for μ to use as its default value when you want to only specify SIGMA .

The multivariate normal cumulative probability at X is defined as the probability that a random vector V , distributed as multivariate normal, will fall within the semi-infinite rectangle with upper limits defined by X , for example, $\Pr\{V(1) \leq X(1), V(2) \leq X(2), \dots, V(d) \leq X(d)\}$.

`y = mvncdf(xl,xu,mu,SIGMA)` returns the multivariate normal cumulative probability evaluated over the rectangle with lower and upper limits defined by x_l and x_u , respectively.

`[y,err] = mvncdf(...)` returns an estimate of the error in y . For bivariate and trivariate distributions, `mvncdf` uses adaptive quadrature on a transformation of the t density, based on methods developed by Drezner and Wesolowsky and by Genz, as described in the references. The default absolute error tolerance for these cases is $1e-8$. For four or more dimensions, `mvncdf` uses a quasi-Monte Carlo integration

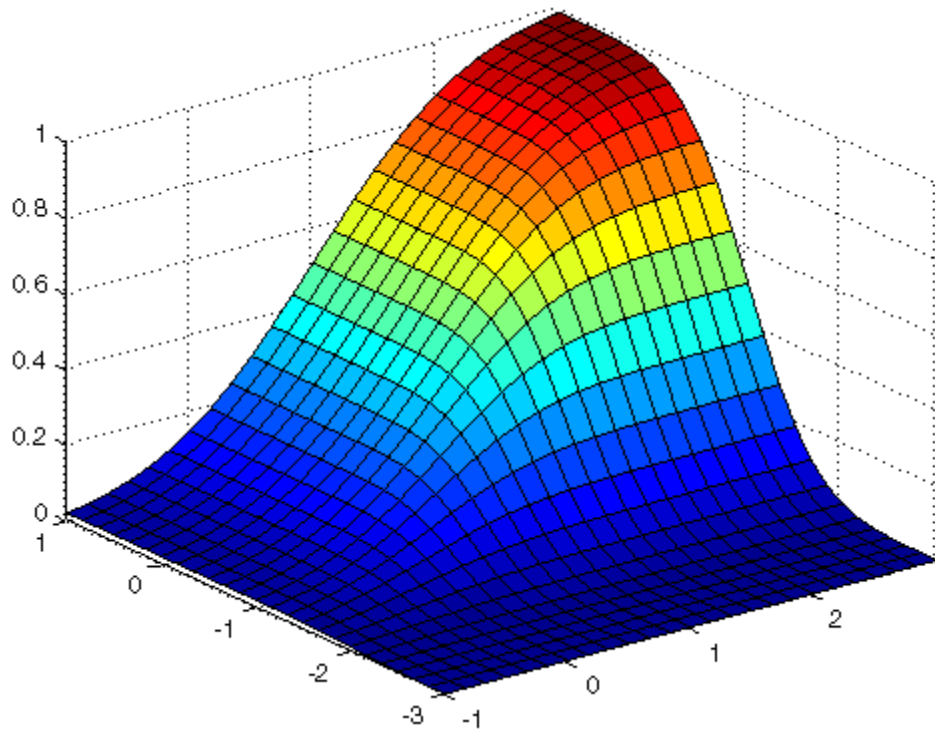
algorithm based on methods developed by Genz and Bretz, as described in the references. The default absolute error tolerance for these cases is $1e-4$.

`[...] = mvncdf(...,options)` specifies control parameters for the numerical integration used to compute `y`. This argument can be created by a call to `statset`. Choices of `statset` parameters:

- `'TolFun'` — Maximum absolute error tolerance. Default is $1e-8$ when $d < 4$, or $1e-4$ when $d \geq 4$.
- `'MaxFunEvals'` — Maximum number of integrand evaluations allowed when $d \geq 4$. Default is $1e7$. `'MaxFunEvals'` is ignored when $d < 4$.
- `'Display'` — Level of display output. Choices are `'off'` (the default), `'iter'`, and `'final'`. `'Display'` is ignored when $d < 4$.

Examples

```
mu = [1 -1]; SIGMA = [.9 .4; .4 .3];  
[X1,X2] = meshgrid(linspace(-1,3,25)',linspace(-3,1,25)');  
X = [X1(:) X2(:)];  
p = mvncdf(X,mu,SIGMA);  
surf(X1,X2,reshape(p,25,25));
```



References

- [1] Drezner, Z. “Computation of the Trivariate Normal Integral.” *Mathematics of Computation*. Vol. 63, 1994, pp. 289–294.
- [2] Drezner, Z., and G. O. Wesolowsky. “On the Computation of the Bivariate Normal Integral.” *Journal of Statistical Computation and Simulation*. Vol. 35, 1989, pp. 101–107.
- [3] Genz, A. “Numerical Computation of Rectangular Bivariate and Trivariate Normal and t Probabilities.” *Statistics and Computing*. Vol. 14, No. 3, 2004, pp. 251–260.
- [4] Genz, A., and F. Bretz. “Numerical Computation of Multivariate t Probabilities with Application to Power Calculation of Multiple

Contrasts.” *Journal of Statistical Computation and Simulation*. Vol. 63, 1999, pp. 361–378.

[5] Genz, A., and F. Bretz. “Comparison of Methods for the Computation of Multivariate t Probabilities.” *Journal of Computational and Graphical Statistics*. Vol. 11, No. 4, 2002, pp. 950–971.

See Also

mvnpdf | mvnrnd

How To

- “Multivariate Normal Distribution” on page B-71

mvnpdf

Purpose Multivariate normal probability density function

Syntax

```
y = mvnpdf(X)
y = mvnpdf(X,MU)
y = mvnpdf(X,MU,SIGMA)
```

Description

`y = mvnpdf(X)` returns the n -by-1 vector `y`, containing the probability density of the multivariate normal distribution with zero mean and identity covariance matrix, evaluated at each row of the n -by- d matrix `X`. Rows of `X` correspond to observations and columns correspond to variables or coordinates.

`y = mvnpdf(X,MU)` returns the density of the multivariate normal distribution with mean `mu` and identity covariance matrix, evaluated at each row of `X`. `MU` is a 1-by- d vector, or an n -by- d matrix. If `MU` is a matrix, the density is evaluated for each row of `X` with the corresponding row of `MU`. `MU` can also be a scalar value, which `mvnpdf` replicates to match the size of `X`.

`y = mvnpdf(X,MU,SIGMA)` returns the density of the multivariate normal distribution with mean `MU` and covariance `SIGMA`, evaluated at each row of `X`. `SIGMA` is a d -by- d matrix, or a d -by- d -by- n array, in which case the density is evaluated for each row of `X` with the corresponding page of `SIGMA`, i.e., `mvnpdf` computes `y(i)` using `X(i,:)` and `SIGMA(:, :, i)`. If the covariance matrix is diagonal, containing variances along the diagonal and zero covariances off the diagonal, `SIGMA` may also be specified as a 1-by- d vector or a 1-by- d -by- n array, containing just the diagonal. Specify `[]` for `MU` to use its default value when you want to specify only `SIGMA`.

If `X` is a 1-by- d vector, `mvnpdf` replicates it to match the leading dimension of `mu` or the trailing dimension of `SIGMA`.

Examples

```
mu = [1 -1];
SIGMA = [.9 .4; .4 .3];
X = mvnrnd(mu,SIGMA,10);
p = mvnpdf(X,mu,SIGMA);
```


See Also

[mvncdf](#) | [mvnrnd](#) | [normpdf](#)

How To

- “Multivariate Normal Distribution” on page B-71

mvregress

Purpose Multivariate linear regression

Syntax

```
beta = mvregress(X,Y)
[beta,Sigma] = mvregress(X,Y)
[beta,Sigma,E,CovB,logL] = mvregress(X,Y)
[ ___ ] = mvregress(X,Y,Name,Value)
```

Description `beta = mvregress(X,Y)` returns a vector of estimated coefficients for a multivariate normal regression of the d -dimensional responses in Y on the design matrices in X .

`mvregress` treats NaN values in X or Y as missing values. Rows with missing values in X are ignored. Missing values in Y are handled according to the estimation `algorithm`.

`[beta,Sigma] = mvregress(X,Y)` also returns the estimated d -by- d variance-covariance matrix of Y .

`[beta,Sigma,E,CovB,logL] = mvregress(X,Y)` returns a matrix of residuals, E , estimated variance-covariance matrix of the regression coefficients, $CovB$, and the value of the log likelihood objective function after the last iteration, $logL$.

`[___] = mvregress(X,Y,Name,Value)` uses additional estimation options specified by one or more name-value pair arguments. You can return any of the output arguments in the previous syntaxes.

Input Arguments

X - Design matrices
matrix | cell array of matrices

Design matrices for the multivariate regression, specified as an N -by- K matrix, or a cell array of d -by- K matrices.

- If $d = 1$, then specify X as a single N -by- K matrix.
- If $d > 1$, then specify X as a cell array of matrices. If you are using the same d -by- K design matrix for all N observations, then X can be

a single cell. Otherwise, specify X as a length- N cell array of d -by- K matrices.

To include a constant term in the regression model, each design matrix should have a column of 1s.

Data Types

single | double | cell

Y - Response variables

matrix

Response variables, specified as an N -by- d matrix. When $d = 1$, `mvregress` treats the values in Y like N independent response values.

Data Types

single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1`, `Value1`, ..., `NameN`, `ValueN`.

Example: `'algorithm','cwlsl','covar0',C` specifies covariance-weighted least squares estimation using the covariance matrix `C`.

algorithm - Estimation algorithm

'mvn' | 'ecm' | 'cwlsl'

Estimation algorithm, specified as the comma-separated pair consisting of 'algorithm' and one of the following strings:

mvregress

'mvn'	Ordinary multivariate normal maximum likelihood estimation.
'ecm'	Maximum likelihood estimation via the ECM algorithm.
'cwlsls'	Covariance-weighted least squares estimation.

The default algorithm depends on the presence of missing data.

- For complete data, the default is 'mvn'.
- If there are any missing responses (indicated by NaN), the default is 'ecm', provided the sample size is sufficient to estimate all parameters. Otherwise, the default algorithm is 'cwlsls'.

Note If `algorithm` has value 'mvn', then `mvregress` removes observations with missing response values before estimation.

Example: 'algorithm','ecm'

beta0 - Initial estimates for regression coefficients

vector

Initial estimates for the regression coefficients, specified as the comma-separated pair consisting of 'beta0' and a vector with K elements. The default value is a vector of 0s.

The `beta0` argument is not used if the estimation `algorithm` is 'mvn'.

For example, suppose `b0` is a K -element vector of initial estimates.

Example: 'beta0',b0

covar0 - Initial estimate for variance-covariance matrix

matrix

Initial estimate for the variance-covariance matrix, Σ , specified as the comma-separated pair consisting of 'covar0' and a symmetric, positive definite, d -by- d matrix. The default value is the identity matrix.

If the estimation algorithm is 'cwls', then mvregress uses covar0 as the weighting matrix at each iteration, without changing it.

For example, suppose C is a valid d -by- d covariance matrix.

Example: 'covar0',C

covtype - Type of variance-covariance matrix

'full' (default) | 'diagonal'

Type of variance-covariance matrix to estimate for Y, specified as the comma-separated pair consisting of 'covtype' and one of 'full' or 'diagonal'.

- If the value is 'full', then mvregress estimates all $d(d + 1)/2$ variance-covariance elements.
- If the value is 'diagonal', then mvregress estimates only the d diagonal elements of the variance-covariance matrix.

Example: 'covtype','diagonal'

maxiter - Maximum number of iterations

100 (default) | positive integer

Maximum number of iterations for the estimation algorithm, specified as the comma-separated pair consisting of 'maxiter' and a positive integer.

Iterations continue until estimates are within the convergence tolerances tolbeta and tolobj, or the maximum number of iterations specified by maxiter is reached. If both tolbeta and tolobj are zero, then mvregress performs maxiter iterations with no convergence tests.

Example: 'maxiter',50

outpuffcn - Function to evaluate each iteration

function handle

Function to evaluate at each iteration, specified as the comma-separated pair consisting of 'outputfcn' and a function handle. The function must return a logical `true` or `false`. At each iteration, `mvregress` evaluates the function. If the result is `true`, iterations stop. Otherwise, iterations continue. For example, you could specify a function that plots or displays current iteration results, and returns `true` if you close the figure.

The function must accept three input arguments, in this order:

- Vector of current coefficient estimates.
- Structure with three fields:

<code>Covar</code>	Current value of the variance-covariance matrix
<code>iteration</code>	Current iteration number
<code>fval</code>	Current value of the loglikelihood objective function

- Text string that takes these three values:

<code>'init'</code>	For when the function is called during initialization
<code>'iter'</code>	For when the function is called after an iteration
<code>'done'</code>	For when called after completion

tolbeta - Convergence tolerance for regression coefficients

`sqrt(eps)` (default) | positive scalar value

Convergence tolerance for regression coefficients, specified as the comma-separated pair consisting of 'tolbeta' and a positive scalar value. The default tolerance is `sqrt(eps)`.

Let \mathbf{b}^t denote the estimate of the coefficient vector at iteration t , and τ_β be the tolerance specified by `tolbeta`. The convergence criterion for regression coefficient estimation is

$$\|\mathbf{b}^t - \mathbf{b}^{t-1}\| < \tau_\beta \sqrt{K} (1 + \|\mathbf{b}^t\|),$$

where K is the length of \mathbf{b}^t and $\|\mathbf{v}\|$ is the norm of a vector \mathbf{v} .

Iterations continue until estimates are within the convergence tolerances `tolbeta` and `tolobj`, or the maximum number of iterations specified by `maxiter` is reached. If both `tolbeta` and `tolobj` are zero, then `mvregress` performs `maxiter` iterations with no convergence tests.

Example: `'tolbeta', 1e-5`

tolobj - Convergence tolerance for loglikelihood objective function

`eps^(3/4)` (default) | positive scalar value

Convergence tolerance for the loglikelihood objective function, specified as the comma-separated pair consisting of `'tolobj'` and a positive scalar value. The default tolerance is `eps^(3/4)`.

Let L^t denote the value of the loglikelihood objective function at iteration t , and τ_ℓ be the tolerance specified by `tolobj`. The convergence criterion for the objective function is

$$|L^t - L^{t-1}| < \tau_\ell (1 + |L^t|).$$

Iterations continue until estimates are within the convergence tolerances `tolbeta` and `tolobj`, or the maximum number of iterations specified by `maxiter` is reached. If both `tolbeta` and `tolobj` are zero, then `mvregress` performs `maxiter` iterations with no convergence tests.

Example: `'tolobj', 1e-5`

varformat - Format for parameter estimate variance-covariance matrix

'beta' (default) | 'full'

Format for the parameter estimate variance-covariance matrix, COVB, specified as the comma-separated pair consisting of 'varformat' and one of these strings:

'beta'	Return the variance-covariance matrix for only the regression coefficient estimates, beta .
'full'	Return the variance-covariance matrix for both the regression coefficient estimates, beta , and the variance-covariance matrix estimate, Sigma .

Example: 'varformat', 'full'

vartype - Type of variance-covariance matrix for parameter estimates

'hessian' (default) | 'fisher'

Type of variance-covariance matrix for parameter estimates, specified as the comma-separated pair consisting of 'vartype' and either 'hessian' or 'fisher'.

- If the value is 'hessian', then `mvregress` uses the Hessian, or observed information, matrix to compute COVB.
- If the value is 'fisher', then `mvregress` uses the complete-data Fisher, or expected information, matrix to compute COVB.

The 'hessian' method takes into account the increase uncertainties due to missing data, while the 'fisher' method does not.

Example: 'vartype', 'fisher'

Output Arguments

beta - Estimated regression coefficients

column vector

Estimated regression coefficients, returned as a K -by-1 vector.

Sigma - Estimate variance-covariance matrix

square matrix

Estimated variance-covariance matrix for the responses in Y , returned as a d -by- d square matrix.

Note The estimated variance-covariance matrix, Σ , is not the sample covariance matrix of the residual matrix, E .

E - Residuals

matrix

Residuals for the fitted regression model, returned as an N -by- d matrix.

If `algorithm` has value 'ecm' or 'cwlsl', then `mvregress` computes the residual values corresponding to missing values in Y as the difference between conditionally-imputed values and the fitted values.

Note If `algorithm` has value 'mvn', then `mvregress` removes observations with missing response values before estimation.

CovB - Parameter estimate variance-covariance matrix

square matrix

Parameter estimate variance-covariance matrix, returned as a square matrix.

- If `varformat` has value 'beta' (the default), then `CovB` is the estimated variance-covariance matrix of the coefficient estimates in `beta`.
- If `varformat` has value 'full', then `CovB` is the estimated variance-covariance matrix of the combined estimates in `beta` and `Sigma`.

logL - Loglikelihood objective function value

scalar value

Loglikelihood objective function value after the last iteration, returned as a scalar value.

Examples

Multivariate Regression Model for Panels with Different Intercepts

Fit a multivariate regression model to panels with different intercepts and common slopes.

Load sample data.

```
load('flu')
```

The dataset array, `flu`, contains national CDC flu estimates, and nine separate regional estimates based on Google® queries.

Extract response and predictor data.

```
Y = double(flu(:,2:end-1));  
[N,d] = size(Y);
```

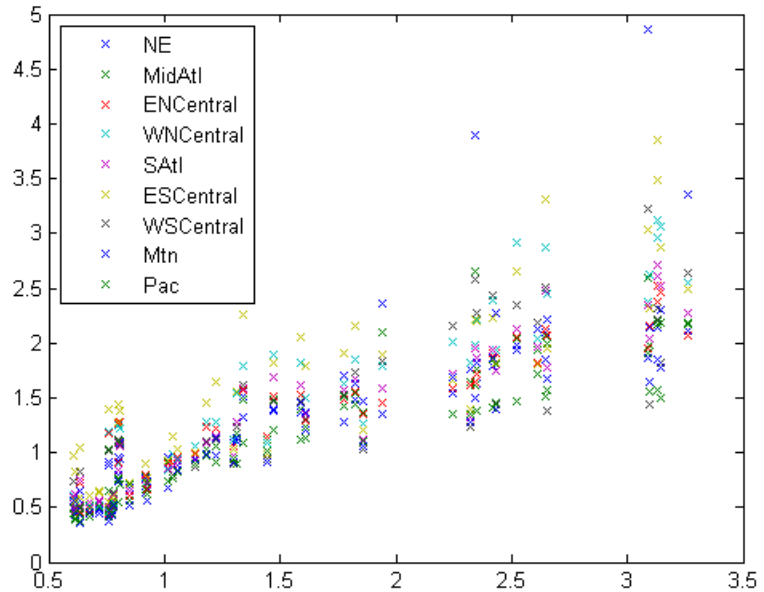
The responses are the Google query estimates. There are observations for every week, so $N = 52$. The dimension of the responses corresponds to the regions, so $d = 9$.

```
x = flu.WtdILI;
```

The predictors are national CDC flu estimates.

```
regions = flu.Properties.VarNames(2:end-1);
```

```
figure()  
plot(x,Y,'x')  
legend(regions,'Location','NorthWest')
```



Fit the multivariate regression model

$$y_{ij} = \alpha_j + \beta x_{ij} + \varepsilon_{ij}, \quad i = 1, \dots, N; \quad j = 1, \dots, d,$$

with correlation between the panels,

$$COV(\varepsilon_{ij}, \varepsilon_{i'j'}) = \sigma_{jj'}, \quad j = 1, \dots, d.$$

There are $K=10$ regression coefficients to estimate: 9 intercept terms and a common slope. The input argument X should be an N -element cell array of d -by- K design matrices.

```
X = cell(N,1);
for i=1:N
    X{i} = [eye(d) repmat(x(i),d,1)];
```

mvregress

```
end
```

```
[beta,Sigma] = mvregress(X,Y);
```

beta contains estimates of the K -dimensional coefficient vector,

$$(\alpha_1, \alpha_2, \dots, \alpha_9, \beta)'$$

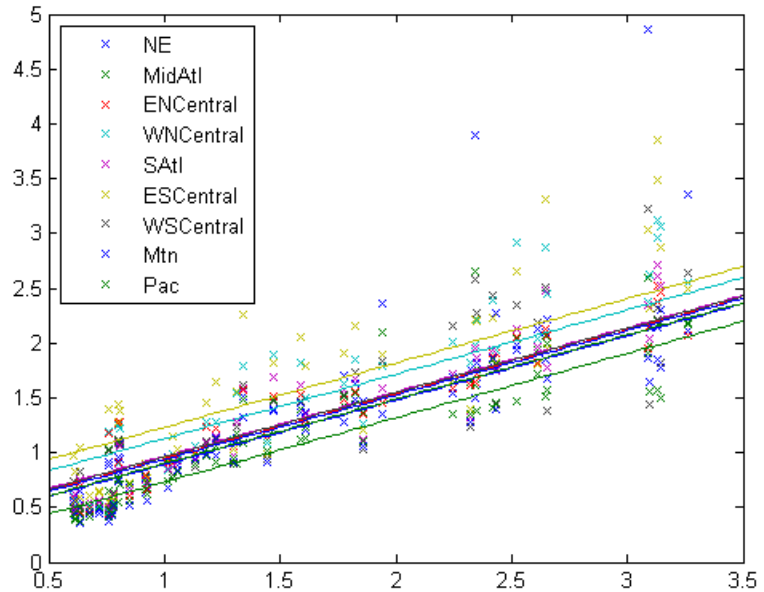
Sigma contains estimates of the d -by- d variance-covariance matrix for the between-panel correlations,

$$\begin{pmatrix} \sigma_{11} & \cdots & \sigma_{1,9} \\ \vdots & \ddots & \vdots \\ \sigma_{9,1} & \cdots & \sigma_{9,9} \end{pmatrix}.$$

Plot the fitted regression model.

```
B = [beta(1:d)'; repmat(beta(end),1,d)];  
xx = linspace(.5,3.5)';  
fits = [ones(size(xx)),xx]*B;
```

```
figure()  
h = plot(x,Y,'x',xx,fits,'-');  
for i = 1:d  
    set(h(d+i),'color',get(h(i),'color'));  
end  
legend(regions,'Location','NorthWest')
```



Multivariate Regression for Panels with Different Slopes

Fit a multivariate regression model to panels with different intercepts and slopes using least squares.

Load sample data.

```
load('flu')
```

The dataset array, `flu`, contains national CDC flu estimates, and nine separate regional estimates based on Google queries.

Extract response and predictor data.

```
Y = double(flu(:,2:end-1));  
[N,d] = size(Y);
```

The responses are the Google query estimates. There are observations for every week, so $N = 52$. The dimension of the responses corresponds to the regions, so $d = 9$.

```
x = flu.WtdILI;
```

The predictors are national CDC flu estimates.

Fit the multivariate regression model

$$y_{ij} = \alpha_j + \beta x_{ij} + \varepsilon_{ij}, \quad i = 1, \dots, N; \quad j = 1, \dots, d,$$

with correlation between the panels,

$$\text{COV}(\varepsilon_{ij}, \varepsilon_{ij'}) = \sigma_{jj'}, \quad j = 1, \dots, d.$$

There are $K=18$ regression coefficients to estimate: 9 intercept terms and 9 slope terms. The input argument X should be an N -element cell array of d -by- K design matrices.

```
X = cell(N,1);  
for i=1:N  
    X{i} = [eye(d) x(i)*eye(d)];  
end
```

```
[beta,Sigma] = mvregress(X,Y,'algorithm','cwlsl');
```

beta contains estimates of the K -dimensional coefficient vector,

$$(\alpha_1, \alpha_2, \dots, \alpha_9, \beta_1, \beta_2, \dots, \beta_9)'$$

Plot the fitted regression model.

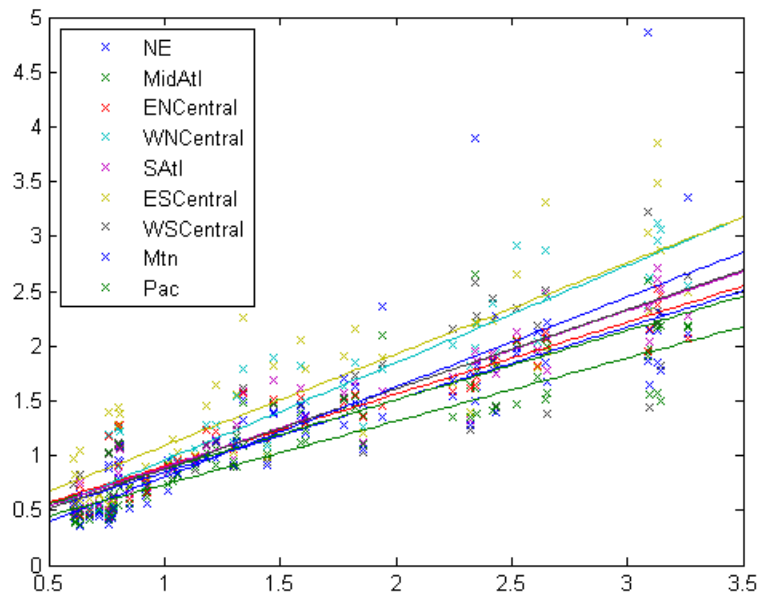
```
B = [beta(1:d)';beta(d+1:end)'];  
xx = linspace(.5,3.5)';  
fits = [ones(size(xx)),xx]*B;  
  
figure()
```

```

h = plot(x,Y,'x',xx,fits,'-');
for i = 1:d
    set(h(d+i),'color',get(h(i),'color'));
end

regions = flu.Properties.VarNames(2:end-1);
legend(regions,'Location','NorthWest')

```



Definitions

Multivariate Normal Regression

Multivariate normal regression is the regression of a d -dimensional response on a design matrix of predictor variables, with normally distributed errors. The errors can be heteroscedastic and correlated.

The model is

$$\mathbf{y}_i = \mathbf{X}_i\beta + \mathbf{e}_i, \quad i = 1, \dots, N,$$

where

- \mathbf{y}_i is a d -dimensional vector of responses.
- \mathbf{X}_i is a d -by- K design matrix of predictor variables.
- β is a K -dimensional vector of regression coefficients.
- \mathbf{e}_i is a d -dimensional vector of error terms, with multivariate normal distribution

$$\mathbf{e}_i \sim MVN_d(\mathbf{0}, \Sigma).$$

Conditionally-Imputed Values

The expectation/conditional maximization ('ecm') and covariance-weighted least squares ('cwlsls') estimation algorithms include imputation of missing response values.

Let $\tilde{\mathbf{y}}$ denote missing observations. The conditionally-imputed values are the expected value of the missing observation given the observed data, $E(\tilde{\mathbf{y}} | \mathbf{y})$.

The joint distribution of the missing and observed responses is a multivariate normal distribution,

$$\begin{pmatrix} \tilde{\mathbf{y}} \\ \mathbf{y} \end{pmatrix} \sim MVN \left\{ \begin{pmatrix} \tilde{\mathbf{X}}\beta \\ \mathbf{X}\beta \end{pmatrix}, \begin{pmatrix} \Sigma_{\tilde{y}} & \Sigma_{\tilde{y}y} \\ \Sigma_{y\tilde{y}} & \Sigma_y \end{pmatrix} \right\}.$$

Using properties of the multivariate normal distribution, the imputed conditional expectation is given by

$$E(\tilde{\mathbf{y}} | \mathbf{y}) = \tilde{\mathbf{X}}\beta + \Sigma_{\tilde{y}y}\Sigma_y^{-1}(\mathbf{y} - \mathbf{X}\beta).$$

Note mvregress only imputes missing response values. Observations with missing values in the design matrix are removed.

References

- [1] Little, Roderick J. A., and Donald B. Rubin. *Statistical Analysis with Missing Data*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 2002.
- [2] Meng, Xiao-Li, and Donald B. Rubin. “Maximum Likelihood Estimation via the ECM Algorithm.” *Biometrika*. Vol. 80, No. 2, 1993, pp. 267–278.
- [3] Sexton, Joe, and A. R. Swensen. “ECM Algorithms that Converge at the Rate of EM.” *Biometrika*. Vol. 87, No. 3, 2000, pp. 651–662.
- [4] Dempster, A. P., N. M. Laird, and D. B. Rubin. “Maximum Likelihood from Incomplete Data via the EM Algorithm.” *Journal of the Royal Statistical Society. Series B*, Vol. 39, No. 1, 1977, pp. 1–37.

See Also

manova1 | mvregresslike

mvregresslike

Purpose Negative log-likelihood for multivariate regression

Syntax
`nlogL = mvregresslike(X,Y,b,SIGMA,alg)`
`[nlogL,COVB] = mvregresslike(...)`
`[nlogL,COVB] = mvregresslike(...,type,format)`

Description `nlogL = mvregresslike(X,Y,b,SIGMA,alg)` computes the negative log-likelihood `nlogL` for a multivariate regression of the d -dimensional multivariate observations in the n -by- d matrix `Y` on the predictor variables in the matrix or cell array `X`, evaluated for the p -by-1 column vector `b` of coefficient estimates and the d -by- d matrix `SIGMA` specifying the covariance of a row of `Y`. If $d = 1$, `X` can be an n -by- p design matrix of predictor variables. For any value of d , `X` can also be a cell array of length n , with each cell containing a d -by- p design matrix for one multivariate observation. If all observations have the same d -by- p design matrix, `X` can be a single cell.

NaN values in `X` or `Y` are taken as missing. Observations with missing values in `X` are ignored. Treatment of missing values in `Y` depends on the algorithm specified by `alg`.

`alg` should match the algorithm used by `mvregress` to obtain the coefficient estimates `b`, and must be one of the following:

- 'ecm' — ECM algorithm
- 'cwlsl' — Least squares conditionally weighted by `SIGMA`
- 'mvm' — Multivariate normal estimates computed after omitting rows with any missing values in `Y`

`[nlogL,COVB] = mvregresslike(...)` also returns an estimated covariance matrix `COVB` of the parameter estimates `b`.

`[nlogL,COVB] = mvregresslike(...,type,format)` specifies the type and format of `COVB`.

`type` is either:

- 'hessian' — To use the Hessian or observed information. This method takes into account the increased uncertainties due to missing data. This is the default.
- 'fisher' — To use the Fisher or expected information. This method uses the complete data expected information, and does not include uncertainty due to missing data.

format is either:

- 'beta' — To compute COVB for b only. This is the default.
- 'full' — To compute COVB for both b and SIGMA.

See Also

mvregress | manova1

How To

- “Multivariate Normal Distribution” on page B-71

mvnrnd

Purpose Multivariate normal random numbers

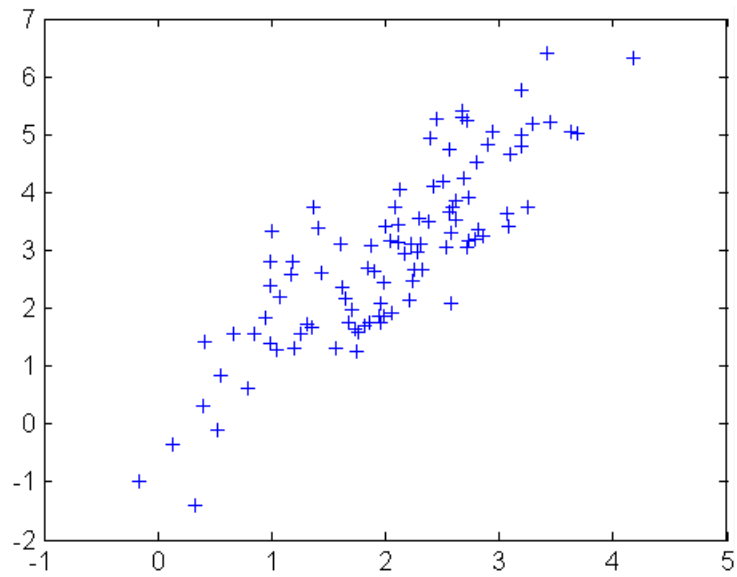
Syntax
`R = mvnrnd(MU,SIGMA)`
`r = mvnrnd(MU,SIGMA,cases)`

Description `R = mvnrnd(MU,SIGMA)` returns an n -by- d matrix `R` of random vectors chosen from the multivariate normal distribution with mean `MU`, and covariance `SIGMA`. `MU` is an n -by- d matrix, and `mvnrnd` generates each row of `R` using the corresponding row of `mu`. `SIGMA` is a d -by- d symmetric positive semi-definite matrix, or a d -by- d -by- n array. If `SIGMA` is an array, `mvnrnd` generates each row of `R` using the corresponding page of `SIGMA`, i.e., `mvnrnd` computes `R(i,:)` using `MU(i,:)` and `SIGMA(:,:,i)`. If the covariance matrix is diagonal, containing variances along the diagonal and zero covariances off the diagonal, `SIGMA` may also be specified as a 1-by- d vector or a 1-by- d -by- n array, containing just the diagonal. If `MU` is a 1-by- d vector, `mvnrnd` replicates it to match the trailing dimension of `SIGMA`.

`r = mvnrnd(MU,SIGMA,cases)` returns a cases-by- d matrix `R` of random vectors chosen from the multivariate normal distribution with a common 1-by- d mean vector `MU`, and a common d -by- d covariance matrix `SIGMA`.

Examples

```
mu = [2 3];  
SIGMA = [1 1.5; 1.5 3];  
r = mvnrnd(mu,SIGMA,100);  
plot(r(:,1),r(:,2),'+')
```

**See Also**

[mvnpdf](#) | [mvncdf](#) | [normrnd](#)

How To

- “Multivariate Normal Distribution” on page B-71

Purpose Multivariate t cumulative distribution function

Syntax

```
y = mvtcdf(X,C,DF)
y = mvtcdf(xl,xu,C,DF)
[y,err] = mvtcdf(...)
[...] = mvntdf(...,options)
```

Description `y = mvtcdf(X,C,DF)` returns the cumulative probability of the multivariate t distribution with correlation parameters `C` and degrees of freedom `DF`, evaluated at each row of `X`. Rows of the n -by- d matrix `X` correspond to observations or points, and columns correspond to variables or coordinates. `y` is an n -by-1 vector.

`C` is a symmetric, positive definite, d -by- d matrix, typically a correlation matrix. If its diagonal elements are not 1, `mvtcdf` scales `C` to correlation form. `mvtcdf` does not rescale `X`. `DF` is a scalar, or a vector with n elements.

The multivariate t cumulative probability at `X` is defined as the probability that a random vector `T`, distributed as multivariate t , will fall within the semi-infinite rectangle with upper limits defined by `X`, i.e., $\Pr\{T(1)\leq X(1), T(2)\leq X(2), \dots, T(d)\leq X(d)\}$.

`y = mvtcdf(xl,xu,C,DF)` returns the multivariate t cumulative probability evaluated over the rectangle with lower and upper limits defined by `xl` and `xu`, respectively.

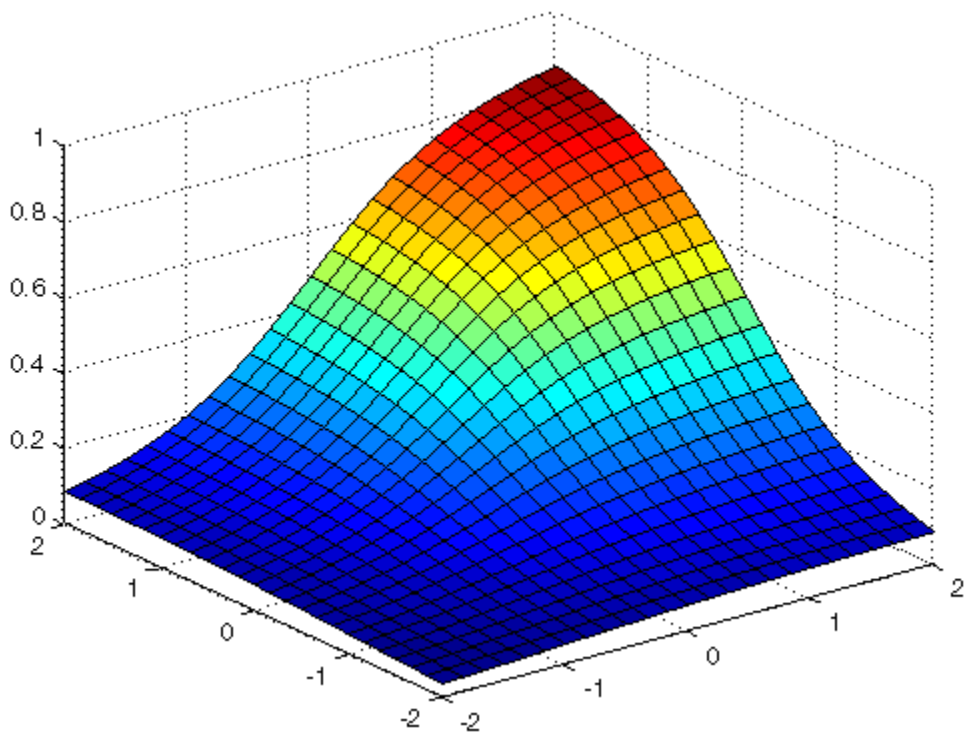
`[y,err] = mvtcdf(...)` returns an estimate of the error in `y`. For bivariate and trivariate distributions, `mvtcdf` uses adaptive quadrature on a transformation of the t density, based on methods developed by Genz, as described in the references. The default absolute error tolerance for these cases is $1e-8$. For four or more dimensions, `mvtcdf` uses a quasi-Monte Carlo integration algorithm based on methods developed by Genz and Bretz, as described in the references. The default absolute error tolerance for these cases is $1e-4$.

`[...] = mvntdf(...,options)` specifies control parameters for the numerical integration used to compute `y`. This argument can be created by a call to `statset`. Choices of `statset` parameters are:

- 'TolFun' — Maximum absolute error tolerance. Default is $1e-8$ when $d < 4$, or $1e-4$ when $d \geq 4$.
- 'MaxFunEvals' — Maximum number of integrand evaluations allowed when $d \geq 4$. Default is $1e7$. 'MaxFunEvals' is ignored when $d < 4$.
- 'Display' — Level of display output. Choices are 'off' (the default), 'iter', and 'final'. 'Display' is ignored when $d < 4$.

Examples

```
C = [1 .4; .4 1]; df = 2;
[X1,X2] = meshgrid(linspace(-2,2,25)',linspace(-2,2,25)');
X = [X1(:) X2(:)];
p = mvtcdf(X,C,df);
surf(X1,X2,reshape(p,25,25));
```



References

- [1] Genz, A. “Numerical Computation of Rectangular Bivariate and Trivariate Normal and t Probabilities.” *Statistics and Computing*. Vol. 14, No. 3, 2004, pp. 251–260.
- [2] Genz, A., and F. Bretz. “Numerical Computation of Multivariate t Probabilities with Application to Power Calculation of Multiple Contrasts.” *Journal of Statistical Computation and Simulation*. Vol. 63, 1999, pp. 361–378.
- [3] Genz, A., and F. Bretz. “Comparison of Methods for the Computation of Multivariate t Probabilities.” *Journal of Computational and Graphical Statistics*. Vol. 11, No. 4, 2002, pp. 950–971.

See Also mvtpdf | mvtrnd

How To • “Multivariate t Distribution” on page B-77

mvtpdf

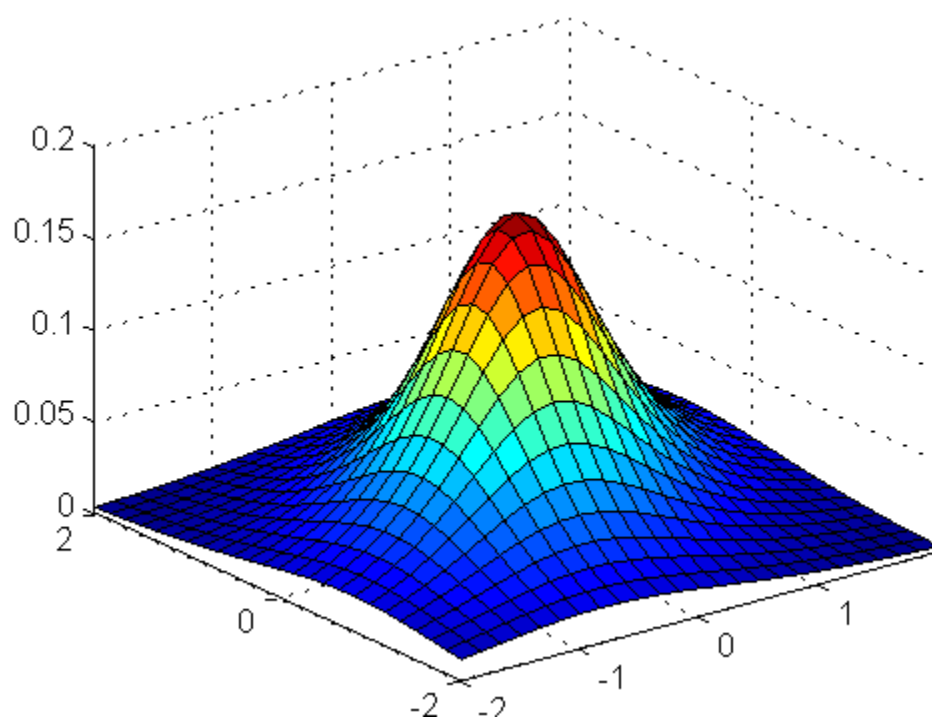
Purpose Multivariate t probability density function

Syntax `y = mvtpdf(X,C,df)`

Description `y = mvtpdf(X,C,df)` returns the probability density of the multivariate t distribution with correlation parameters `C` and degrees of freedom `df`, evaluated at each row of `X`. Rows of the n -by- d matrix `X` correspond to observations or points, and columns correspond to variables or coordinates. `C` is a symmetric, positive definite, d -by- d matrix, typically a correlation matrix. If its diagonal elements are not 1, `mvtpdf` scales `C` to correlation form. `mvtcdf` does not rescale `X`. `df` is a scalar, or a vector with n elements. `y` is an n -by-1 vector.

Examples Visualize a multivariate t distribution:

```
[X1,X2] = meshgrid(linspace(-2,2,25)',linspace(-2,2,25)');
X = [X1(:) X2(:)];
C = [1 .4; .4 1];
df = 2;
p = mvtpdf(X,C,df);
surf(X1,X2,reshape(p,25,25))
```

**See Also**

`mvtcdf` | `mvtrnd`

How To

- “Multivariate t Distribution” on page B-77

mvtrnd

Purpose Multivariate t random numbers

Syntax `R = mvtrnd(C,df,cases)`
`R = mvtrnd(C,df)`

Description `R = mvtrnd(C,df,cases)` returns a matrix of random numbers chosen from the multivariate t distribution, where `C` is a correlation matrix. `df` is the degrees of freedom and is either a scalar or is a vector with `cases` elements. If `p` is the number of columns in `C`, then the output `R` has `cases` rows and `p` columns.

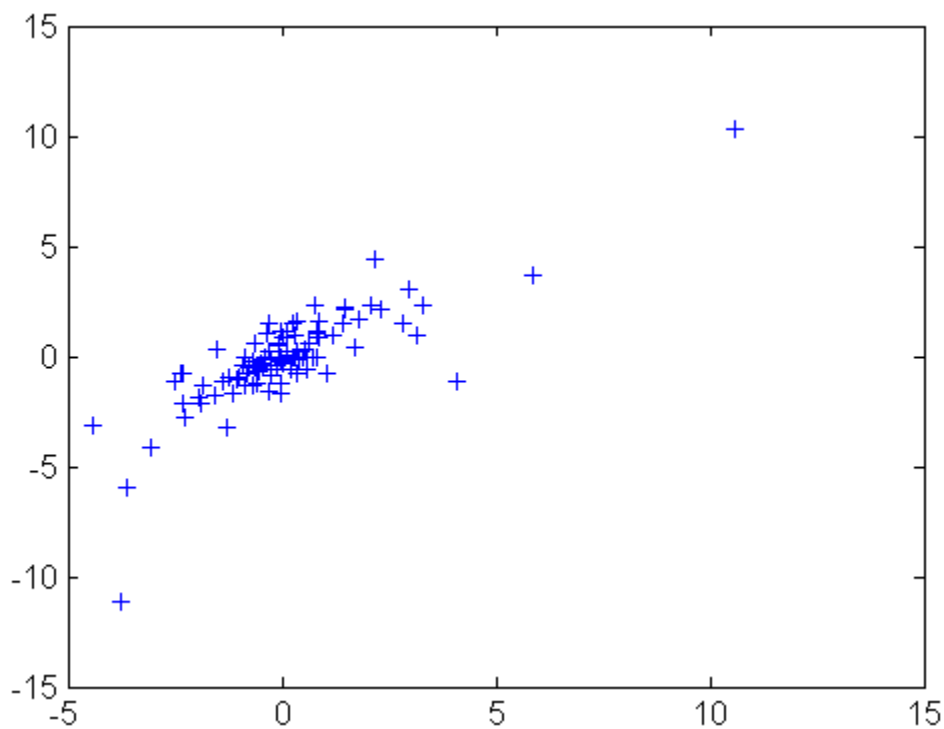
Let `t` represent a row of `R`. Then the distribution of `t` is that of a vector having a multivariate normal distribution with mean 0, variance 1, and covariance matrix `C`, divided by an independent chi-square random value having `df` degrees of freedom. The rows of `R` are independent.

`C` must be a square, symmetric and positive definite matrix. If its diagonal elements are not all 1 (that is, if `C` is a covariance matrix rather than a correlation matrix), `mvtrnd` rescales `C` to transform it to a correlation matrix before generating the random numbers.

`R = mvtrnd(C,df)` returns a single random number from the multivariate t distribution.

Examples

```
SIGMA = [1 0.8;0.8 1];  
R = mvtrnd(SIGMA,3,100);  
plot(R(:,1),R(:,2),'+')
```

**See Also**

[mvtpdf](#) | [mvtcdf](#)

How To

- “Multivariate t Distribution” on page B-77

cvpartition.N property

Purpose Number of observations (including observations with missing group values)

Description Number of observations (including observations with missing group values).

Purpose	Naive Bayes classifier	
Description	A NaiveBayes object defines a Naive Bayes classifier. A Naive Bayes classifier assigns a new observation to the most probable class, assuming the features are conditionally independent given the class value.	
Construction	NaiveBayes	Create NaiveBayes object
Methods	disp	Display NaiveBayes classifier object
	display	Display NaiveBayes classifier object
	fit	Create Naive Bayes classifier object by fitting training data
	posterior	Compute posterior probability of each class for test data
	predict	Predict class label for test data
	subsasgn	Subscripted reference for NaiveBayes object
	subsref	Subscripted reference for NaiveBayes object
Properties	CIsNonEmpty	Flag for non-empty classes
	CLevels	Class levels
	CNames	Class names
	CPrior	Class priors

NaiveBayes

Dist	Distribution names
NClasses	Number of classes
NDims	Number of dimensions
Params	Parameter estimates

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

Examples

Predict the class label using the Naive Bayes classifier:

```
load fisheriris
```

Use the default Gaussian distribution and a confusion matrix:

```
O1 = NaiveBayes.fit(meas,species);  
C1 = O1.predict(meas);  
cMat1 = confusionmat(species,C1)
```

This returns:

```
cMat1 =  
  
    50     0     0  
     0    47     3  
     0     3    47
```

Use the Gaussian distribution for features 1 and 3 and use the kernel density estimation for features 2 and 4:

```
O2 = NaiveBayes.fit(meas,species,'dist',...  
{'normal','kernel','normal','kernel'});  
C2 = O2.predict(meas);  
cMat2 = confusionmat(species,C2)
```

This returns:

cMat2 =

50	0	0
0	47	3
0	3	47

References

[1] Mitchell, T. (1997) Machine Learning, McGraw Hill.

[2] Vangelis M., Ion A., and Geogios P. Spam Filtering with Naive Bayes - Which Naive Bayes? (2006) Third Conference on Email and Anti-Spam.

[3] George H. John and Pat Langley. Estimating continuous distributions in bayesian classifiers (1995) the Eleventh Conference on Uncertainty in Artificial Intelligence.

How To

- “Naive Bayes Classification” on page 12-36
- “Grouping Variables” on page 2-72

NaiveBayes

Purpose Create NaiveBayes object

Description You cannot create a NaiveBayes classifier by calling the constructor. Use `NaiveBayes.fit` to create a NaiveBayes classifier by fitting the object to training data.

See Also `fit`

Purpose Covariance ignoring NaN values

Syntax

```
Y = nancov(X)
Y = nancov(X1,X2)
Y = nancov(...,1)
Y = nancov(...,'pairwise')
```

Description `Y = nancov(X)` is the covariance `cov` of `X`, computed after removing observations with NaN values.

For vectors `x`, `nancov(x)` is the sample variance of the remaining elements, once NaN values are removed. For matrices `X`, `nancov(X)` is the sample covariance of the remaining observations, once observations (rows) containing any NaN values are removed.

`Y = nancov(X1,X2)`, where `X1` and `X2` are matrices with the same number of elements, is equivalent to `nancov(X)`, where `X = [X1(:) X2(:)]`.

`nancov` removes the mean from each variable (column for matrix `X`) before calculating `Y`. If `n` is the number of remaining observations after removing observations with NaN values, `nancov` normalizes `Y` by either `n - 1` or `n`, depending on whether `n > 1` or `n = 1`, respectively. To specify normalization by `n`, use `Y = nancov(...,1)`.

`Y = nancov(...,'pairwise')` computes `Y(i,j)` using rows with no NaN values in columns `i` or `j`. The result `Y` may not be a positive definite matrix.

Examples Generate random data for two variables (columns) with random missing values:

```
X = rand(10,2);
p = randperm(numel(X));
X(p(1:5)) = NaN
X =
    0.8147    0.1576
         NaN         NaN
    0.1270    0.9572
```

```
0.9134      NaN
0.6324      NaN
0.0975      0.1419
0.2785      0.4218
0.5469      0.9157
0.9575      0.7922
0.9649      NaN
```

Establish a correlation between a third variable and the other two variables:

```
X(:,3) = sum(X,2)
X =
```

```
0.8147      0.1576      0.9723
      NaN      NaN      NaN
0.1270      0.9572      1.0842
0.9134      NaN      NaN
0.6324      NaN      NaN
0.0975      0.1419      0.2394
0.2785      0.4218      0.7003
0.5469      0.9157      1.4626
0.9575      0.7922      1.7497
0.9649      NaN      NaN
```

Compute the covariance matrix for the three variables after removing observations (rows) with NaN values:

```
Y = nancov(X)
Y =
```

```
0.1311      0.0096      0.1407
0.0096      0.1388      0.1483
0.1407      0.1483      0.2890
```

See Also

[NaN](#) | [cov](#) | [var](#) | [nanvar](#)

Purpose Maximum ignoring NaN values

Syntax

```
y = nanmax(X)
Y = nanmax(X1,X2)
y = nanmax(X,[],dim)
[y,indices] = nanmax(...)
```

Description `y = nanmax(X)` is the maximum max of `X`, computed after removing NaN values.

For vectors `x`, `nanmax(x)` is the maximum of the remaining elements, once NaN values are removed. For matrices `X`, `nanmax(X)` is a row vector of column maxima, once NaN values are removed. For multidimensional arrays `X`, `nanmax` operates along the first nonsingleton dimension.

`Y = nanmax(X1,X2)` returns an array `Y` the same size as `X1` and `X2` with `Y(i,j) = nanmax(X1(i,j),X2(i,j))`. Scalar inputs are expanded to an array of the same size as the other input.

`y = nanmax(X,[],dim)` operates along the dimension `dim` of `X`.

`[y,indices] = nanmax(...)` also returns the row indices of the maximum values for each column in the vector `indices`.

Examples Find column maxima and their indices for data with missing values:

```
X = magic(3);
X([1 6:9]) = repmat(NaN,1,5)
X =
    NaN     1    NaN
     3     5    NaN
     4    NaN    NaN
[y,indices] = nanmax(X)
y =
     4     5    NaN
indices =
     3     2     1
```

See Also NaN | max | nanmin

nanmean

Purpose Mean ignoring NaN values

Syntax
`y = nanmean(X)`
`y = nanmean(X,dim)`

Description `y = nanmean(X)` is the mean of `X`, computed after removing NaN values. For vectors `x`, `nanmean(x)` is the mean of the remaining elements, once NaN values are removed. For matrices `X`, `nanmean(X)` is a row vector of column means, once NaN values are removed. For multidimensional arrays `X`, `nanmean` operates along the first nonsingleton dimension. `y = nanmean(X,dim)` takes the mean along dimension `dim` of `X`.

Note If `X` contains a vector of all NaN values along some dimension, the vector is empty once the NaN values are removed, so the sum of the remaining elements is 0. Since the mean involves division by 0, its value is NaN. The output NaN is not a mean of NaN values.

Examples Find column means for data with missing values:

```
X = magic(3);
X([1 6:9]) = repmat(NaN,1,5)
X =
    NaN     1    NaN
     3     5    NaN
     4    NaN    NaN
y = nanmean(X)
y =
    3.5000    3.0000    NaN
```

See Also NaN | mean | nanmedian

Purpose Median ignoring NaN values

Syntax `y = nanmedian(X)`
`y = nanmedian(X,dim)`

Description `y = nanmedian(X)` is the median of `X`, computed after removing NaN values.

For vectors `x`, `nanmedian(x)` is the median of the remaining elements, once NaN values are removed. For matrices `X`, `nanmedian(X)` is a row vector of column medians, once NaN values are removed. For multidimensional arrays `X`, `nanmedian` operates along the first nonsingleton dimension.

`y = nanmedian(X,dim)` takes the mean along dimension `dim` of `X`.

Examples Find column medians for data with missing values:

```
X = magic(3);
X([1 6:9]) = repmat(NaN,1,5)
X =
    NaN     1    NaN
     3     5    NaN
     4    NaN    NaN
y = nanmedian(X)
y =
    3.5000    3.0000    NaN
```

See Also `NaN` | `median` | `nanmean`

nanmin

Purpose Minimum ignoring NaN values

Syntax

```
y = nanmin(X)
Y = nanmin(X1,X2)
y = nanmin(X,[],dim)
[y,indices] = nanmin(...)
```

Description `y = nanmin(X)` is the minimum `min` of `X`, computed after removing NaN values.

For vectors `x`, `nanmin(x)` is the minimum of the remaining elements, once NaN values are removed. For matrices `X`, `nanmin(X)` is a row vector of column minima, once NaN values are removed. For multidimensional arrays `X`, `nanmin` operates along the first nonsingleton dimension.

`Y = nanmin(X1,X2)` returns an array `Y` the same size as `X1` and `X2` with `Y(i,j) = nanmin(X1(i,j),X2(i,j))`. Scalar inputs are expanded to an array of the same size as the other input.

`y = nanmin(X,[],dim)` operates along the dimension `dim` of `X`.

`[y,indices] = nanmin(...)` also returns the row indices of the minimum values for each column in the vector `indices`.

Examples Find column minima and their indices for data with missing values:

```
X = magic(3);
X([1 6:9]) = repmat(NaN,1,5)
X =
    NaN     1    NaN
     3     5    NaN
     4    NaN    NaN
[y,indices] = nanmin(X)
y =
     3     1    NaN
indices =
     2     1     1
```

See Also NaN | min | nanmax

Purpose

Standard deviation ignoring NaN values

Syntax

```
y = nanstd(X)
y = nanstd(X,1)
y = nanstd(X,flag,dim)
```

Description

`y = nanstd(X)` is the standard deviation `std` of `X`, computed after removing NaN values.

For vectors `x`, `nanstd(x)` is the sample standard deviation of the remaining elements, once NaN values are removed. For matrices `X`, `nanstd(X)` is a row vector of column sample standard deviations, once NaN values are removed. For multidimensional arrays `X`, `nanstd` operates along the first nonsingleton dimension.

If n is the number of remaining observations after removing observations with NaN values, `nanstd` normalizes `y` by $n-1$. To specify normalization by n , use `y = nanstd(X,1)`.

`y = nanstd(X,flag,dim)` takes the standard deviation along the dimension `dim` of `X`. The `flag` is 0 or 1 to specify normalization by $n-1$ or n , respectively, where n is the number of remaining observations after removing observations with NaN values.

Examples

Find column standard deviations for data with missing values:

```
X = magic(3);
X([1 6:9]) = repmat(NaN,1,5)
X =
    NaN     1     NaN
     3     5     NaN
     4    NaN     NaN
y = nanstd(X)
y =
    0.7071    2.8284    NaN
```

See Also

NaN | std | nanvar | nanmean

nansum

Purpose Sum ignoring NaN values

Syntax
`y = nansum(X)`
`y = nansum(X,dim)`

Description `y = nansum(X)` is the sum of `X`, computed after removing NaN values. For vectors `x`, `nansum(x)` is the sum of the remaining elements, once NaN values are removed. For matrices `X`, `nansum(X)` is a row vector of column sums, once NaN values are removed. For multidimensional arrays `X`, `nansum` operates along the first nonsingleton dimension. `y = nansum(X,dim)` takes the sum along dimension `dim` of `X`.

Note If `X` contains a vector of all NaN values along some dimension, the vector is empty once the NaN values are removed, so the sum of the remaining elements is 0. The output 0 is not a sum of NaN values.

Examples Find column sums for data with missing values:

```
X = magic(3);
X([1 6:9]) = repmat(NaN,1,5)
X =
    NaN     1    NaN
     3     5    NaN
     4    NaN    NaN
y = nansum(X)
y =
     7     6     0
```

See Also NaN | sum

Purpose Variance, ignoring NaN values

Syntax

```
y = nanvar(X)
y = nanvar(X,1)
y = nanvar(X,w)
y = nanvar(X,w,dim)
```

Description `y = nanvar(X)` is the variance `var` of `X`, computed after removing NaN values.

For vectors `x`, `nanvar(x)` is the sample variance of the remaining elements, once NaN values are removed. For matrices `X`, `nanvar(X)` is a row vector of column sample variances, once NaN values are removed. For multidimensional arrays `X`, `nanvar` operates along the first nonsingleton dimension.

`nancov` removes the mean from each variable (column for matrix `X`) before calculating `Y`. If n is the number of remaining observations after removing observations with NaN values, `nanvar` normalizes `y` by either $n - 1$ or n , depending on whether $n > 1$ or $n = 1$, respectively. To specify normalization by n , use `y = nanvar(X,1)`.

`y = nanvar(X,w)` computes the variance using the weight vector `w`. The length of `w` must equal the length of the dimension over which `nanvar` operates, and its elements must be nonnegative. Elements of `X` corresponding to NaN values of `w` are ignored.

`y = nanvar(X,w,dim)` takes the variance along the dimension `dim` of `X`. Set `w` to `[]` to use the default normalization by $n - 1$.

Examples Find column standard deviations for data with missing values:

```
X = magic(3);
X([1 6:9]) = repmat(NaN,1,5)
X =
    NaN     1    NaN
     3     5    NaN
     4    NaN    NaN
y = nanvar(X)
```

nanvar

```
y =  
    0.5000    8.0000    NaN
```

See Also

[NaN](#) | [var](#) | [nanstd](#) | [nanmean](#)

Purpose Negative binomial cumulative distribution function

Syntax `Y = nbincdf(X,R,P)`

Description `Y = nbincdf(X,R,P)` computes the negative binomial cdf at each of the values in `X` using the corresponding number of successes, `R` and probability of success in a single trial, `P`. `X`, `R`, and `P` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `Y`. A scalar input for `X`, `R`, or `P` is expanded to a constant array with the same dimensions as the other inputs.

The negative binomial cdf is

$$y = F(x | r, p) = \sum_{i=0}^x \binom{r+i-1}{i} p^r q^i I_{(0,1,\dots)}(i)$$

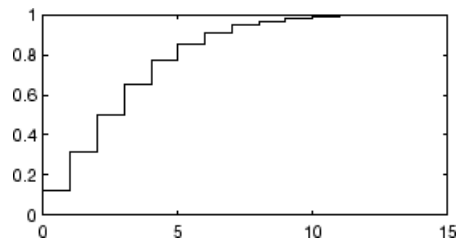
The simplest motivation for the negative binomial is the case of successive random trials, each having a constant probability `P` of success. The number of *extra* trials you must perform in order to observe a given number `R` of successes has a negative binomial distribution. However, consistent with a more general interpretation of the negative binomial, `nbincdf` allows `R` to be any positive value, including nonintegers. When `R` is noninteger, the binomial coefficient in the definition of the cdf is replaced by the equivalent expression

$$\frac{\Gamma(r+i)}{\Gamma(r)\Gamma(i+1)}$$

Examples

```
x = (0:15);
p = nbincdf(x,3,0.5);
stairs(x,p)
```

nbincdf



See Also

[cdf](#) | [nbinpdf](#) | [nbininv](#) | [nbinstat](#) | [nbinfit](#) | [nbinrnd](#)

How To

- “Negative Binomial Distribution” on page B-85

Purpose	Negative binomial parameter estimates
Syntax	<pre>parmhat = nbinfit(data) [parmhat,parmci] = nbinfit(data,alpha) [...] = nbinfit(data,alpha,options)</pre>
Description	<p><code>parmhat = nbinfit(data)</code> returns the maximum likelihood estimates (MLEs) of the parameters of the negative binomial distribution given the data in the vector <code>data</code>.</p> <p><code>[parmhat,parmci] = nbinfit(data,alpha)</code> returns MLEs and 100(1-alpha) percent confidence intervals. By default, <code>alpha = 0.05</code>, which corresponds to 95% confidence intervals.</p> <p><code>[...] = nbinfit(data,alpha,options)</code> accepts a structure, <code>options</code>, that specifies control parameters for the iterative algorithm the function uses to compute maximum likelihood estimates. The negative binomial fit function accepts an <code>options</code> structure which you can create using the function <code>statset</code>. Enter <code>statset('nbinfit')</code> to see the names and default values of the parameters that <code>nbinfit</code> accepts in the <code>options</code> structure. See the reference page for <code>statset</code> for more information about these options.</p>
	<hr/> <p>Note The variance of a negative binomial distribution is greater than its mean. If the sample variance of the data in <code>data</code> is less than its sample mean, <code>nbinfit</code> cannot compute MLEs. You should use the <code>poissfit</code> function instead.</p> <hr/>
See Also	<code>nbincdf</code> <code>nbiniinv</code> <code>nbinpdf</code> <code>nbinrnd</code> <code>nbinstat</code> <code>mle</code> <code>statset</code>
How To	<ul style="list-style-type: none">• “Negative Binomial Distribution” on page B-85

nbininv

Purpose Negative binomial inverse cumulative distribution function

Syntax `X = nbininv(Y,R,P)`

Description `X = nbininv(Y,R,P)` returns the inverse of the negative binomial cdf with corresponding number of successes, `R` and probability of success in a single trial, `P`. Since the binomial distribution is discrete, `nbininv` returns the least integer `X` such that the negative binomial cdf evaluated at `X` equals or exceeds `Y`. `Y`, `R`, and `P` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `X`. A scalar input for `Y`, `R`, or `P` is expanded to a constant array with the same dimensions as the other inputs.

The simplest motivation for the negative binomial is the case of successive random trials, each having a constant probability `P` of success. The number of *extra* trials you must perform in order to observe a given number `R` of successes has a negative binomial distribution. However, consistent with a more general interpretation of the negative binomial, `nbininv` allows `R` to be any positive value, including nonintegers.

Examples How many times would you need to flip a fair coin to have a 99% probability of having observed 10 heads?

```
flips = nbininv(0.99,10,0.5) + 10
flips =
    33
```

Note that you have to flip at least 10 times to get 10 heads. That is why the second term on the right side of the equals sign is a 10.

See Also `icdf` | `nbincdf` | `nbinpdf` | `nbinstat` | `nbinfit` | `nbinrnd`

How To • “Negative Binomial Distribution” on page B-85

Purpose Negative binomial probability density function

Syntax `Y = nbinpdf(X,R,P)`

Description `Y = nbinpdf(X,R,P)` returns the negative binomial pdf at each of the values in `X` using the corresponding number of successes, `R` and probability of success in a single trial, `P`. `X`, `R`, and `P` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `Y`. A scalar input for `X`, `R`, or `P` is expanded to a constant array with the same dimensions as the other inputs. Note that the density function is zero unless the values in `X` are integers.

The negative binomial pdf is

$$y = f(x | r, p) = \binom{r+x-1}{x} p^r q^x I_{(0,1,\dots)}(x)$$

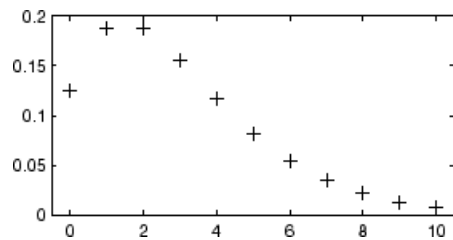
The simplest motivation for the negative binomial is the case of successive random trials, each having a constant probability `P` of success. The number of *extra* trials you must perform in order to observe a given number `R` of successes has a negative binomial distribution. However, consistent with a more general interpretation of the negative binomial, `nbinpdf` allows `R` to be any positive value, including nonintegers. When `R` is noninteger, the binomial coefficient in the definition of the pdf is replaced by the equivalent expression

$$\frac{\Gamma(r+x)}{\Gamma(r)\Gamma(x+1)}$$

Examples

```
x = (0:10);  
y = nbinpdf(x,3,0.5);  
plot(x,y, '+')  
set(gca, 'Xlim', [-0.5,10.5])
```

nbinpdf



See Also

[pdf](#) | [nbincdf](#) | [nbininv](#) | [nbinstat](#) | [nbinfit](#) | [nbinrnd](#)

How To

- “Negative Binomial Distribution” on page B-85

Purpose	Negative binomial random numbers
Syntax	<pre>RND = nbinrnd(R,P) RND = nbinrnd(R,P,m,n,...) RND = nbinrnd(R,P,[m,n,...])</pre>
Description	<p><code>RND = nbinrnd(R,P)</code> is a matrix of random numbers chosen from a negative binomial distribution with corresponding number of successes, <code>R</code> and probability of success in a single trial, <code>P</code>. <code>R</code> and <code>P</code> can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of <code>RND</code>. A scalar input for <code>R</code> or <code>P</code> is expanded to a constant array with the same dimensions as the other input.</p> <p><code>RND = nbinrnd(R,P,m,n,...)</code> or <code>RND = nbinrnd(R,P,[m,n,...])</code> generates an <code>m-by-n-by-...</code> array. The <code>R</code>, <code>P</code> parameters can each be scalars or arrays of the same size as <code>R</code>.</p> <p>The simplest motivation for the negative binomial is the case of successive random trials, each having a constant probability <code>P</code> of success. The number of <i>extra</i> trials you must perform in order to observe a given number <code>R</code> of successes has a negative binomial distribution. However, consistent with a more general interpretation of the negative binomial, <code>nbinrnd</code> allows <code>R</code> to be any positive value, including nonintegers.</p>
Examples	<p>Suppose you want to simulate a process that has a defect probability of 0.01. How many units might Quality Assurance inspect before finding three defective items?</p> <pre>r = nbinrnd(3,0.01,1,6)+3 r = 496 142 420 396 851 178</pre>
See Also	<code>random</code> <code>nbinpdf</code> <code>nbincdf</code> <code>nbininv</code> <code>nbinstat</code> <code>nbinfit</code>
How To	<ul style="list-style-type: none"> “Negative Binomial Distribution” on page B-85

nbinstat

Purpose Negative binomial mean and variance

Syntax `[M,V] = nbinstat(R,P)`

Description `[M,V] = nbinstat(R,P)` returns the mean of and variance for the negative binomial distribution with corresponding number of successes, `R` and probability of success in a single trial, `P`. `R` and `P` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `M` and `V`. A scalar input for `R` or `P` is expanded to a constant array with the same dimensions as the other input.

The mean of the negative binomial distribution with parameters r and p is rq / p , where $q = 1 - p$. The variance is rq / p^2 .

The simplest motivation for the negative binomial is the case of successive random trials, each having a constant probability `P` of success. The number of *extra* trials you must perform in order to observe a given number `R` of successes has a negative binomial distribution. However, consistent with a more general interpretation of the negative binomial, `nbinstat` allows `R` to be any positive value, including nonintegers.

Examples

```
p = 0.1:0.2:0.9;
r = 1:5;
[R,P] = meshgrid(r,p);
[M,V] = nbinstat(R,P)
M =
    9.0000    18.0000    27.0000    36.0000    45.0000
    2.3333    4.6667    7.0000    9.3333    11.6667
    1.0000    2.0000    3.0000    4.0000    5.0000
    0.4286    0.8571    1.2857    1.7143    2.1429
    0.1111    0.2222    0.3333    0.4444    0.5556

V =
   90.0000  180.0000  270.0000  360.0000  450.0000
   7.7778  15.5556  23.3333  31.1111  38.8889
   2.0000   4.0000   6.0000   8.0000  10.0000
```

0.6122 1.2245 1.8367 2.4490 3.0612
0.1235 0.2469 0.3704 0.4938 0.6173

See Also

[nbinpdf](#) | [nbincdf](#) | [nbininv](#) | [nbinfit](#) | [nbinrnd](#)

How To

- “Negative Binomial Distribution” on page B-85

ncfcdf

Purpose Noncentral F cumulative distribution function

Syntax $P = \text{ncfcdf}(X, \text{NU1}, \text{NU2}, \text{DELTA})$

Description $P = \text{ncfcdf}(X, \text{NU1}, \text{NU2}, \text{DELTA})$ computes the noncentral F cdf at each of the values in X using the corresponding numerator degrees of freedom in NU1 , denominator degrees of freedom in NU2 , and positive noncentrality parameters in DELTA . NU1 , NU2 , and DELTA can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of P . A scalar input for X , NU1 , NU2 , or DELTA is expanded to a constant array with the same dimensions as the other inputs.

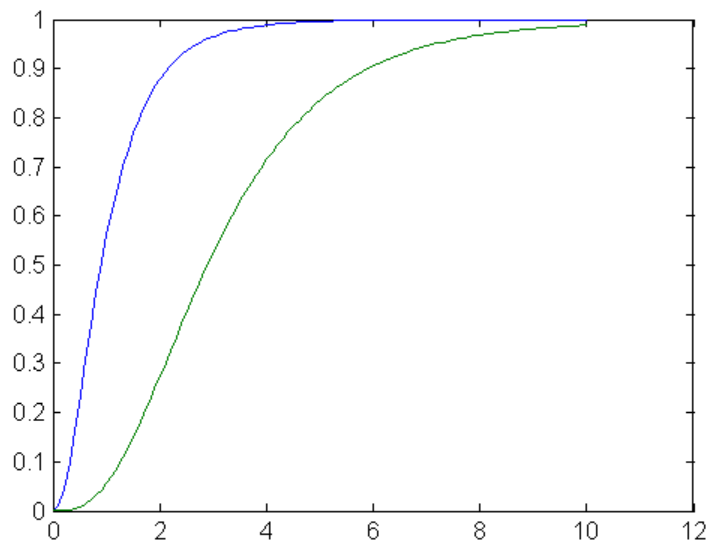
The noncentral F cdf is

$$F(x | v_1, v_2, \delta) = \sum_{j=0}^{\infty} \left(\frac{\left(\frac{1}{2}\delta\right)^j}{j!} e^{-\frac{\delta}{2}} \right) I\left(\frac{v_1 \cdot x}{v_2 + v_1 \cdot x} \middle| \frac{v_1}{2} + j, \frac{v_2}{2}\right)$$

where $I(x | a, b)$ is the incomplete beta function with parameters a and b .

Examples Compare the noncentral F cdf with $\delta = 10$ to the F cdf with the same number of numerator and denominator degrees of freedom (5 and 20 respectively).

```
x = (0.01:0.1:10.01)';  
p1 = ncfcdf(x,5,20,10);  
p = fcdf(x,5,20);  
plot(x,p,'-',x,p1,'-')
```

**References**

[1] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 189–200.

See Also

[cdf](#) | [ncfpdf](#) | [ncfinv](#) | [ncfstat](#) | [ncfrnd](#)

How To

- “Noncentral F Distribution” on page B-91

ncfinv

Purpose Noncentral F inverse cumulative distribution function

Syntax `X = ncfinv(P,NU1,NU2,DELTA)`

Description `X = ncfinv(P,NU1,NU2,DELTA)` returns the inverse of the noncentral F cdf with numerator degrees of freedom `NU1`, denominator degrees of freedom `NU2`, and positive noncentrality parameter `DELTA` for the corresponding probabilities in `P`. `P`, `NU1`, `NU2`, and `DELTA` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `X`. A scalar input for `P`, `NU1`, `NU2`, or `DELTA` is expanded to a constant array with the same dimensions as the other inputs.

Examples One hypothesis test for comparing two sample variances is to take their ratio and compare it to an F distribution. If the numerator and denominator degrees of freedom are 5 and 20 respectively, then you reject the hypothesis that the first variance is equal to the second variance if their ratio is less than that computed below.

```
critical = finv(0.95,5,20)
critical =
    2.7109
```

Suppose the truth is that the first variance is twice as big as the second variance. How likely is it that you would detect this difference?

```
prob = 1 - nfcdf(critical,5,20,2)
prob =
    0.1297
```

If the true ratio of variances is 2, what is the typical (median) value you would expect for the F statistic?

```
ncfinv(0.5,5,20,2)
ans =
    1.2786
```


References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. Hoboken, NJ: Wiley-Interscience, 2000.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 189–200.

See Also

icdf | ncfcdf | ncfpdf | ncfstat | ncfrnd

How To

• “Noncentral F Distribution” on page B-91

ncfpdf

Purpose Noncentral F probability density function

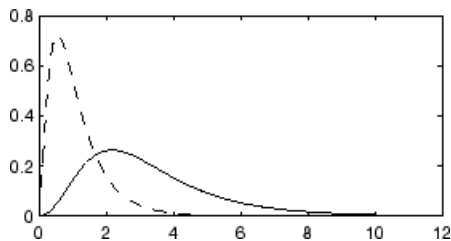
Syntax $Y = \text{ncfpdf}(X, \text{NU1}, \text{NU2}, \text{DELTA})$

Description $Y = \text{ncfpdf}(X, \text{NU1}, \text{NU2}, \text{DELTA})$ computes the noncentral F pdf at each of the values in X using the corresponding numerator degrees of freedom in NU1 , denominator degrees of freedom in NU2 , and positive noncentrality parameters in DELTA . X , NU1 , NU2 , and DELTA can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of Y . A scalar input for NU1 , NU2 , or DELTA is expanded to a constant array with the same dimensions as the other inputs.

The F distribution is a special case of the noncentral F where $\delta = 0$. As δ increases, the distribution flattens like the plot in the example.

Examples Compare the noncentral F pdf with $\delta = 10$ to the F pdf with the same number of numerator and denominator degrees of freedom (5 and 20 respectively).

```
x = (0.01:0.1:10.01)';  
p1 = ncfpdf(x,5,20,10);  
p = fpdf(x,5,20);  
plot(x,p,'-',x,p1,'-')
```



References [1] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 189–200.

See Also pdf | ncfcdf | ncfinv | ncfstat | ncfrnd

How To

- “Noncentral F Distribution” on page B-91

ncfrnd

Purpose Noncentral F random numbers

Syntax
R = ncfrnd(NU1,NU2,DELTA)
R = ncfrnd(NU1,NU2,DELTA,m,n,...)
R = ncfrnd(NU1,NU2,DELTA,[m,n,...])

Description R = ncfrnd(NU1,NU2,DELTA) returns a matrix of random numbers chosen from the noncentral F distribution with corresponding numerator degrees of freedom in NU1, denominator degrees of freedom in NU2, and positive noncentrality parameters in DELTA. NU1, NU2, and DELTA can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of R. A scalar input for NU1, NU2, or DELTA is expanded to a constant matrix with the same dimensions as the other inputs.

R = ncfrnd(NU1,NU2,DELTA,m,n,...) or R = ncfrnd(NU1,NU2,DELTA,[m,n,...]) generates an m-by-n-by-... array. The NU1, NU2, DELTA parameters can each be scalars or arrays of the same size as R.

Examples Compute six random numbers from a noncentral F distribution with 10 numerator degrees of freedom, 100 denominator degrees of freedom and a noncentrality parameter, δ , of 4.0. Compare this to the F distribution with the same degrees of freedom.

```
r = ncfrnd(10,100,4,1,6)
r =
  2.5995  0.8824  0.8220  1.4485  1.4415  1.4864
```

```
r1 = frnd(10,100,1,6)
r1 =
  0.9826  0.5911  1.0967  0.9681  2.0096  0.6598
```

References [1] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 189–200.

See Also

random | ncfpdf | ncfcdf | ncfinv | ncfstat

How To

- “Noncentral F Distribution” on page B-91

ncfstat

Purpose Noncentral F mean and variance

Syntax `[M,V] = ncfstat(NU1,NU2,DELTA)`

Description `[M,V] = ncfstat(NU1,NU2,DELTA)` returns the mean of and variance for the noncentral F pdf with corresponding numerator degrees of freedom in NU1, denominator degrees of freedom in NU2, and positive noncentrality parameters in DELTA. NU1, NU2, and DELTA can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of M and V. A scalar input for NU1, NU2, or DELTA is expanded to a constant array with the same dimensions as the other input.

The mean of the noncentral F distribution with parameters ν_1 , ν_2 , and δ is

$$\frac{\nu_2(\delta + \nu_1)}{\nu_1(\nu_2 - 2)}$$

where $\nu_2 > 2$.

The variance is

$$2\left(\frac{\nu_2}{\nu_1}\right)^2 \left[\frac{(\delta + \nu_1)^2 + (2\delta + \nu_1)(\nu_2 - 2)}{(\nu_2 - 2)^2(\nu_2 - 4)} \right]$$

where $\nu_2 > 4$.

Examples

```
[m,v]= ncfstat(10,100,4)
m =
    1.4286
v =
    0.4252
```

References [1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 73–74.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 189–200.

See Also

ncfpdf | ncfcdf | ncfinv | ncfrnd

How To

- “Noncentral F Distribution” on page B-91

NaiveBayes.NClasses property

Purpose Number of classes

Description The NClasses property specifies the number of classes in the grouping variable used to create the Naive Bayes classifier.

gmdistribution.NComponents property

Purpose Number k of mixture components

Description The number k of mixture components.

nctcdf

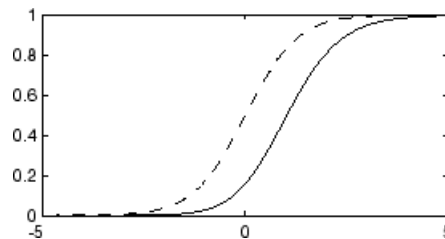
Purpose Noncentral t cumulative distribution function

Syntax $P = \text{nctcdf}(X, \text{NU}, \text{DELTA})$

Description $P = \text{nctcdf}(X, \text{NU}, \text{DELTA})$ computes the noncentral t cdf at each of the values in X using the corresponding degrees of freedom in NU and noncentrality parameters in DELTA . X , NU , and DELTA can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of P . A scalar input for X , NU , or DELTA is expanded to a constant array with the same dimensions as the other inputs.

Examples Compare the noncentral t cdf with $\text{DELTA} = 1$ to the t cdf with the same number of degrees of freedom (10).

```
x = (-5:0.1:5)';  
p1 = nctcdf(x,10,1);  
p = tcdf(x,10);  
plot(x,p,'-',x,p1,'-')
```



References [1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 147–148.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 201–219.

See Also [cdf](#) | [nctpdf](#) | [nctinv](#) | [nctstat](#) | [nctrnd](#)

How To

- “Noncentral t Distribution” on page B-93

nctinv

Purpose Noncentral t inverse cumulative distribution function

Syntax `X = nctinv(P,NU,DELTA)`

Description `X = nctinv(P,NU,DELTA)` returns the inverse of the noncentral t cdf with `NU` degrees of freedom and noncentrality parameter `DELTA` for the corresponding probabilities in `P`. `P`, `NU`, and `DELTA` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `X`. A scalar input for `P`, `NU`, or `DELTA` is expanded to a constant array with the same dimensions as the other inputs.

Examples

```
x = nctinv([0.1 0.2],10,1)
x =
    -0.2914    0.1618
```

References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 147–148.

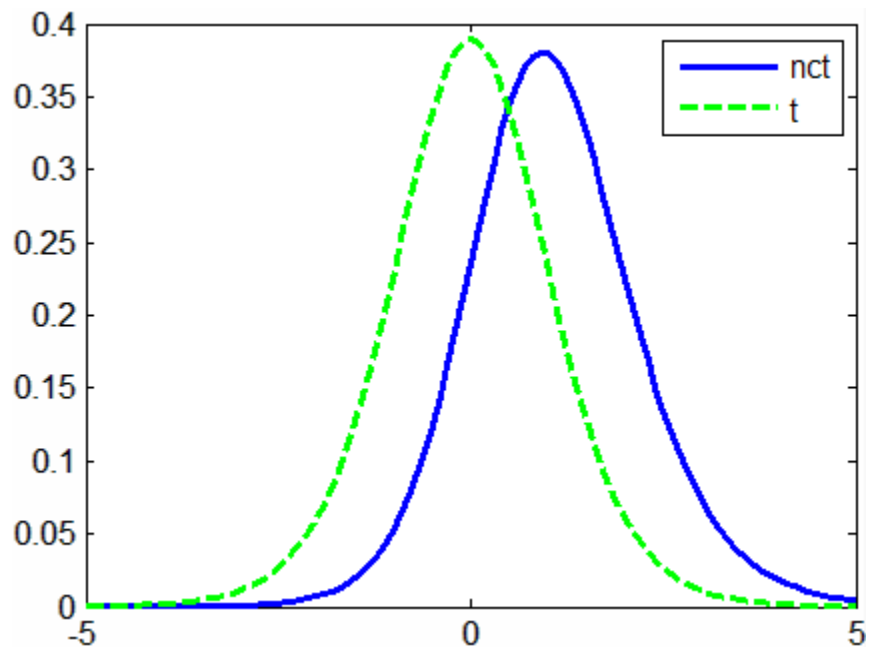
[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 201–219.

See Also `icdf` | `nctcdf` | `nctpdf` | `nctstat` | `nctrnd`

How To

- “Noncentral t Distribution” on page B-93

Purpose	Noncentral t probability density function
Syntax	$Y = \text{nctpdf}(X,V,DELTA)$
Description	$Y = \text{nctpdf}(X,V,DELTA)$ computes the noncentral t pdf at each of the values in X using the corresponding degrees of freedom in V and noncentrality parameters in $DELTA$. Vector or matrix inputs for X , V , and $DELTA$ must have the same size, which is also the size of Y . A scalar input for X , V , or $DELTA$ is expanded to a constant matrix with the same dimensions as the other inputs.
Examples	<p>Compare the noncentral t pdf with $DELTA = 1$ to the t pdf with the same number of degrees of freedom (10):</p> <pre>x = (-5:0.1:5)'; nct = nctpdf(x,10,1); t = tpdf(x,10); plot(x,nct,'b-','LineWidth',2) hold on plot(x,t,'g--','LineWidth',2) legend('nct','t')</pre>



References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 147–148.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 201–219.

See Also

pdf | nctcdf | nctinv | nctstat | nctrnd

How To

- “Noncentral t Distribution” on page B-93

Purpose	Noncentral t random numbers
Syntax	$R = \text{nctrnd}(V, \text{DELTA})$ $R = \text{nctrnd}(V, \text{DELTA}, m, n, \dots)$ $R = \text{nctrnd}(V, \text{DELTA}, [m, n, \dots])$
Description	<p>$R = \text{nctrnd}(V, \text{DELTA})$ returns a matrix of random numbers chosen from the noncentral T distribution using the corresponding degrees of freedom in V and noncentrality parameters in DELTA. V and DELTA can be vectors, matrices, or multidimensional arrays. A scalar input for V or DELTA is expanded to a constant array with the same dimensions as the other input.</p> <p>$R = \text{nctrnd}(V, \text{DELTA}, m, n, \dots)$ or $R = \text{nctrnd}(V, \text{DELTA}, [m, n, \dots])$ generates an m-by-n-by-... array. The V, DELTA parameters can each be scalars or arrays of the same size as R.</p>
Examples	<pre>nctrnd(10, 1, 5, 1) ans = 1.6576 1.0617 1.4491 0.2930 3.6297</pre>
References	<p>[1] Evans, M., N. Hastings, and B. Peacock. <i>Statistical Distributions</i>. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 147–148.</p> <p>[2] Johnson, N., and S. Kotz. <i>Distributions in Statistics: Continuous Univariate Distributions-2</i>. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 201–219.</p>
See Also	random nctpdf nctcdf nctinv nctstat
How To	• “Noncentral t Distribution” on page B-93

nctstat

Purpose Noncentral t mean and variance

Syntax `[M,V] = nctstat(NU,DELTA)`

Description `[M,V] = nctstat(NU,DELTA)` returns the mean of and variance for the noncentral t pdf with NU degrees of freedom and noncentrality parameter $DELTA$. NU and $DELTA$ can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of M and V . A scalar input for NU or $DELTA$ is expanded to a constant array with the same dimensions as the other input.

The mean of the noncentral t distribution with parameters ν and δ is

$$\frac{\delta(\nu/2)^{1/2}\Gamma((\nu-1)/2)}{\Gamma(\nu/2)}$$

where $\nu > 1$.

The variance is

$$\frac{\nu}{(\nu-2)}(1+\delta^2) - \frac{\nu}{2}\delta^2 \left[\frac{\Gamma((\nu-1)/2)}{\Gamma(\nu/2)} \right]^2$$

where $\nu > 2$.

Examples `[m,v] = nctstat(10,1)`

`m =`
`1.0837`

`v =`
`1.3255`

References [1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 147–148.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 201–219.

See Also

nctpdf | nctcdf | nctinv | nctrnd

How To

- “Noncentral t Distribution” on page B-93

Purpose Noncentral chi-square cumulative distribution function

Syntax `P = ncx2cdf(X,V,DELTA)`

Description `P = ncx2cdf(X,V,DELTA)` computes the noncentral chi-square cdf at each of the values in `X` using the corresponding degrees of freedom in `V` and positive noncentrality parameters in `DELTA`. `X`, `V`, and `DELTA` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `P`. A scalar input for `X`, `V`, or `DELTA` is expanded to a constant array with the same dimensions as the other inputs.

Some texts refer to this distribution as the generalized Rayleigh, Rayleigh-Rice, or Rice distribution.

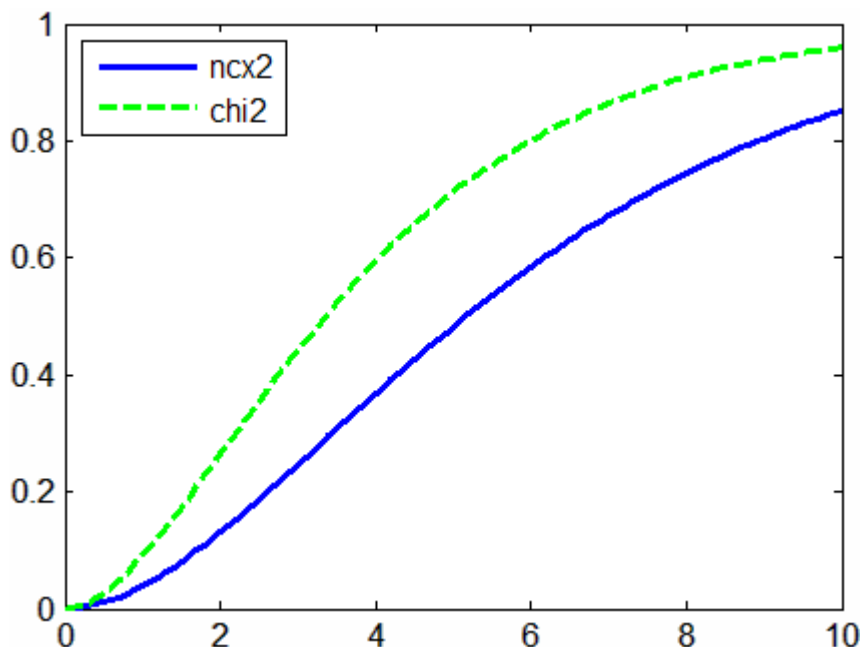
The noncentral chi-square cdf is

$$F(x|v,\delta) = \sum_{j=0}^{\infty} \left(\frac{\left(\frac{1}{2}\delta\right)^j}{j!} e^{-\frac{\delta}{2}} \right) \Pr\left[\chi_{v+2j}^2 \leq x\right]$$

Examples Compare the noncentral chi-square cdf with `DELTA = 2` to the chi-square cdf with the same number of degrees of freedom (4):

```
x = (0:0.1:10)';
ncx2 = ncx2cdf(x,4,2);
chi2 = chi2cdf(x,4);

plot(x,ncx2,'b-','LineWidth',2)
hold on
plot(x,chi2,'g--','LineWidth',2)
legend('ncx2','chi2','Location','NW')
```

**References**

[1] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 130–148.

See Also

[cdf](#) | [ncx2pdf](#) | [ncx2inv](#) | [ncx2stat](#) | [ncx2rnd](#)

How To

- “Noncentral Chi-Square Distribution” on page B-89

Purpose Noncentral chi-square inverse cumulative distribution function

Syntax `X = ncx2inv(P,V,DELTA)`

Description `X = ncx2inv(P,V,DELTA)` returns the inverse of the noncentral chi-square cdf using the corresponding degrees of freedom in `V` and positive noncentrality parameters in `DELTA`, at the corresponding probabilities in `P`. `P`, `V`, and `DELTA` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `X`. A scalar input for `P`, `V`, or `DELTA` is expanded to a constant array with the same dimensions as the other inputs.

Algorithms `ncx2inv` uses Newton's method to converge to the solution.

Examples

```
ncx2inv([0.01 0.05 0.1],4,2)
ans =
    0.4858    1.1498    1.7066
```

References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 50–52.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 130–148.

See Also `icdf` | `ncx2cdf` | `ncx2pdf` | `ncx2stat` | `ncx2rnd`

How To

- “Noncentral Chi-Square Distribution” on page B-89

Purpose Noncentral chi-square probability density function

Syntax `Y = ncx2pdf(X,V,DELTA)`

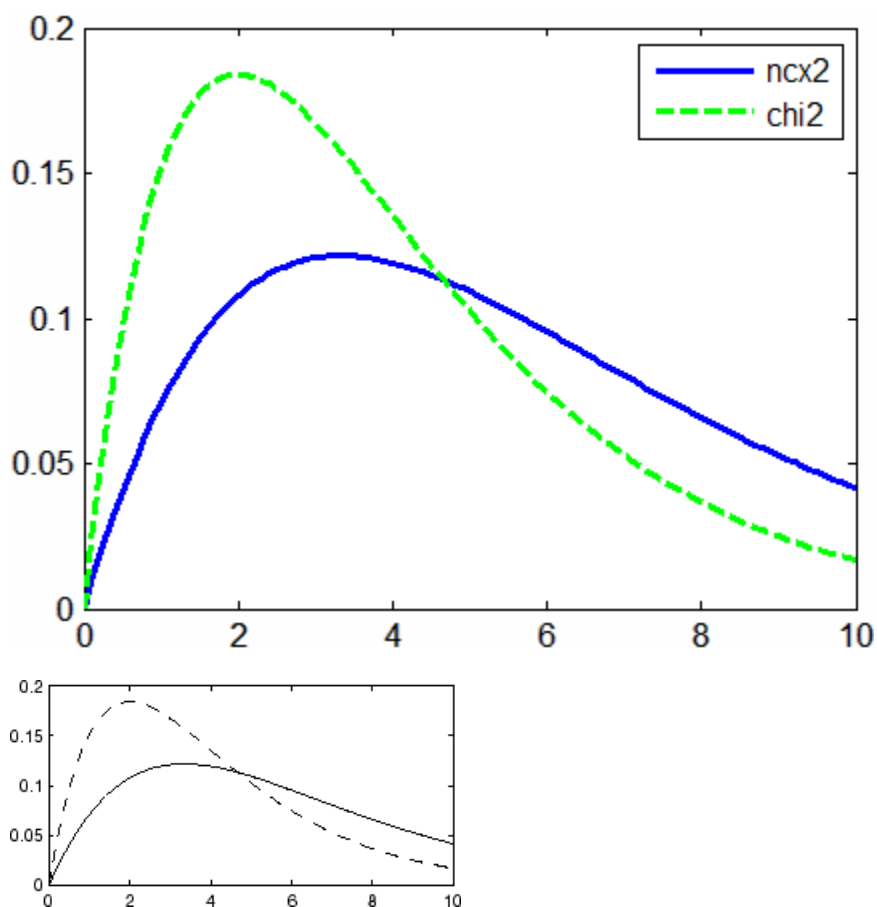
Description `Y = ncx2pdf(X,V,DELTA)` computes the noncentral chi-square pdf at each of the values in `X` using the corresponding degrees of freedom in `V` and positive noncentrality parameters in `DELTA`. Vector or matrix inputs for `X`, `V`, and `DELTA` must have the same size, which is also the size of `Y`. A scalar input for `X`, `V`, or `DELTA` is expanded to a constant array with the same dimensions as the other inputs.

Some texts refer to this distribution as the generalized Rayleigh, Rayleigh-Rice, or Rice distribution.

Examples Compare the noncentral chi-square pdf with `DELTA = 2` to the chi-square pdf with the same number of degrees of freedom (4):

```
x = (0:0.1:10)';
ncx2 = ncx2pdf(x,4,2);
chi2 = chi2pdf(x,4);

plot(x,ncx2,'b-', 'LineWidth',2)
hold on
plot(x,chi2,'g--', 'LineWidth',2)
legend('ncx2','chi2')
```



References

[1] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 130–148.

See Also

[pdf](#) | [ncx2cdf](#) | [ncx2inv](#) | [ncx2stat](#) | [ncx2rnd](#)

How To

- “Noncentral Chi-Square Distribution” on page B-89

Purpose Noncentral chi-square random numbers

Syntax
`R = ncx2rnd(V,DELTA)`
`R = ncx2rnd(V,DELTA,m,n,...)`
`R = ncx2rnd(V,DELTA,[m,n,...])`

Description `R = ncx2rnd(V,DELTA)` returns a matrix of random numbers chosen from the noncentral chi-square distribution using the corresponding degrees of freedom in `V` and positive noncentrality parameters in `DELTA`. `V` and `DELTA` can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of `R`. A scalar input for `V` or `DELTA` is expanded to a constant array with the same dimensions as the other input.

`R = ncx2rnd(V,DELTA,m,n,...)` or `R = ncx2rnd(V,DELTA,[m,n,...])` generates an `m`-by-`n`-by-... array. The `V`, `DELTA` parameters can each be scalars or arrays of the same size as `R`.

Examples

```
ncx2rnd(4,2,6,3)
ans =
    6.8552    5.9650   11.2961
    5.2631    4.2640    5.9495
    9.1939    6.7162    3.8315
   10.3100    4.4828    7.1653
    2.1142    1.9826    4.6400
    3.8852    5.3999    0.9282
```

References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 50–52.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 130–148.

See Also `random` | `ncx2pdf` | `ncx2cdf` | `ncx2inv` | `ncx2stat`

How To • “Noncentral Chi-Square Distribution” on page B-89

Purpose Noncentral chi-square mean and variance

Syntax `[M,V] = ncx2stat(NU,DELTA)`

Description `[M,V] = ncx2stat(NU,DELTA)` returns the mean of and variance for the noncentral chi-square pdf with NU degrees of freedom and noncentrality parameter DELTA. NU and DELTA can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of M and V. A scalar input for NU or DELTA is expanded to a constant array with the same dimensions as the other input.

The mean of the noncentral chi-square distribution with parameters v and δ is $v+\delta$, and the variance is $2(v+2\delta)$.

Examples

```
[m,v] = ncx2stat(4,2)
m =
    6
v =
   16
```

References [1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. 2nd ed., Hoboken, NJ: John Wiley & Sons, Inc., 1993, pp. 50–52.

[2] Johnson, N., and S. Kotz. *Distributions in Statistics: Continuous Univariate Distributions-2*. Hoboken, NJ: John Wiley & Sons, Inc., 1970, pp. 130–148.

See Also `ncx2pdf` | `ncx2cdf` | `ncx2inv` | `ncx2rnd`

How To • “Noncentral Chi-Square Distribution” on page B-89

Purpose Number of dimensions of categorical array

Syntax `n = ndims(A)`

Description `n = ndims(A)` returns the number of dimensions in the categorical array `A`. The number of dimensions in an array is always greater than or equal to 2. Trailing singleton dimensions are ignored. Put simply, `ndims(A)` is `length(size(A))`.

See Also `size`

gmdistribution.NDimensions property

Purpose Dimension d of multivariate Gaussian distributions

Description The dimension d of the multivariate Gaussian distributions.

Purpose Number of dimensions of dataset array

Syntax `n = ndims(A)`

Description `n = ndims(A)` returns the number of dimensions in the dataset A. The number of dimensions in an array is always 2.

See Also `size`

grandset.ndims

Purpose Number of dimensions in matrix

Syntax `n = ndims(p)`

Description `n = ndims(p)` returns the number of dimensions in the matrix that is created by the syntax `p(:, :)`. Since this is always a 2-D matrix, `n` is always equal to 2.

See Also `grandset` | `size`

NaiveBayes.NDims property

Purpose Number of dimensions

Description The NDims property specifies the number of dimensions, which is equal to the number of features in the training data used to create the Naive Bayes classifier.

Purpose Not equal relation for handles

Syntax `h1 ~= h2`

Description Handles are equal if they are handles for the same object and are unequal otherwise.

`h1 ~= h2` performs element-wise comparisons between handle arrays `h1` and `h2`. `h1` and `h2` must be of the same dimensions unless one is a scalar. The result is a logical array of the same dimensions, where each element is an element-wise `~=` result.

If one of `h1` or `h2` is scalar, scalar expansion is performed and the result will match the dimensions of the array that is not scalar.

`tf = ne(h1, h2)` stores the result in a logical array of the same dimensions.

See Also `grandstream` | `eq` | `ge` | `gt` | `le` | `lt`

Purpose	Nearest neighbor search object
Description	NeighborSearcher is an abstract class used for nearest neighbor search. You cannot create instances of this class directly. Instead, create an instance of a derived class such as ExhaustiveSearcher or KDTreeSearcher either by calling the derived class constructor or by calling the function createns.
Construction	NeighborSearcher is an abstract class. You cannot create instances of this class directly. You can construct an object in a subclass, such as KDTreeSearcher or ExhaustiveSearcher, either by calling the subclass constructors or by using the createns function.
Properties	x A matrix used to create the object. Distance A string specifying a built-in distance metric (applies to both ExhaustiveSearcher and KDTreeSearcher) or a function handle (only applies to ExhaustiveSearcher) that you provide when you create the object. This property is the default distance metric used when you call the knnsearch method to find nearest neighbors for future query points. DistParameter Specifies the additional parameter for the chosen distance metric. The value is: <ul style="list-style-type: none">• If 'Distance' is 'minkowski': A positive scalar indicating the exponent of the Minkowski distance. (Applies for both ExhaustiveSearcher and KDTreeSearcher.)• If 'Distance' is 'mahalanobis': A positive definite matrix representing the covariance matrix used for computing the Mahalanobis distance. (Only applies for ExhaustiveSearcher.)

NeighborSearcher

- If 'Distance' is 'seuclidean': A vector representing the scale value of the data when computing the 'seuclidean' distance. (Only applies for ExhaustiveSearcher.)
- Otherwise: Empty.

See Also

`createns` | `KDTreeSearcher` | `ExhaustiveSearcher`

Purpose	Generate quasi-random point set
Syntax	<code>X = net(p,n)</code>
Description	<p><code>X = net(p,n)</code> returns the first n points X from the point set p of the <code>grandset</code> class. X is n-by-d, where d is the dimension of the point set.</p> <p>Objects p of the <code>@grandset</code> class encapsulate properties of a specified quasi-random sequence. Values of the point set are not generated and stored in memory until p is accessed using <code>net</code> or parenthesis indexing.</p>
Examples	<p>Use <code>haltonset</code> to generate a 3-D Halton point set, skip the first 1000 values, and then retain every 101st point:</p> <pre>p = haltonset(3,'Skip',1e3,'Leap',1e2) p = Halton point set in 3 dimensions (8.918019e+013 points) Properties: Skip : 1000 Leap : 100 ScrambleMethod : none</pre> <p>Use <code>scramble</code> to apply reverse-radix scrambling:</p> <pre>p = scramble(p,'RR2') p = Halton point set in 3 dimensions (8.918019e+013 points) Properties: Skip : 1000 Leap : 100 ScrambleMethod : RR2</pre> <p>Use <code>net</code> to generate the first four points:</p> <pre>X0 = net(p,4) X0 = 0.0928 0.6950 0.0029 0.6958 0.2958 0.8269</pre>

0.3013	0.6497	0.4141
0.9087	0.7883	0.2166

Use parenthesis indexing to generate every third point, up to the 11th point:

```
X = p(1:3:11, :)
```

```
X =
```

0.0928	0.6950	0.0029
0.9087	0.7883	0.2166
0.3843	0.9840	0.9878
0.6831	0.7357	0.7923

See Also

[haltonset](#) | [sobolset](#) | [grandstream](#)

CompactClassificationDiscriminant.nLinearCoeffs

Purpose	Number of nonzero linear coefficients
Syntax	<code>ncoeffs = nLinearCoeffs(obj)</code> <code>ncoeffs = nLinearCoeffs(obj,delta)</code>
Description	<code>ncoeffs = nLinearCoeffs(obj)</code> returns the number of nonzero linear coefficients in the linear discriminant model <code>obj</code> . <code>ncoeffs = nLinearCoeffs(obj,delta)</code> returns the number of nonzero linear coefficients for threshold parameter <code>delta</code> .
Input Arguments	obj Discriminant analysis classifier, produced using <code>ClassificationDiscriminant.fit</code> . delta Scalar or vector value of the Delta parameter. See “Gamma and Delta” on page 20-1457.
Output Arguments	ncoeffs Nonnegative integer, the number of nonzero coefficients in the discriminant analysis model <code>obj</code> . If you call <code>nLinearCoeffs</code> with a <code>delta</code> argument, <code>ncoeffs</code> is the number of nonzero linear coefficients for threshold parameter <code>delta</code> . If <code>delta</code> is a vector, <code>ncoeffs</code> is a vector with the same number of elements. If <code>obj</code> is a quadratic discriminant model, <code>ncoeffs</code> is the number of predictors in <code>obj</code> .
Definitions	Gamma and Delta Regularization is the process of finding a small set of predictors that yield an effective predictive model. For linear discriminant analysis, there are two parameters, γ and δ , that control regularization as follows. <code>cvshrink</code> helps you select appropriate values of the parameters.

Compact Classification Discriminant.nLinear Coeffs

Let Σ represent the covariance matrix of the data X , and let \hat{X} be the centered data (the data X minus the mean by class). Define

$$D = \text{diag}(\hat{X}^T * \hat{X}).$$

The regularized covariance matrix $\tilde{\Sigma}$ is

$$\tilde{\Sigma} = (1 - \gamma)\Sigma + \gamma D.$$

Whenever $\gamma \geq \text{MinGamma}$, $\tilde{\Sigma}$ is nonsingular.

Let μ_k be the mean vector for those elements of X in class k , and let μ_0 be the global mean vector (the mean of the rows of X). Let C be the correlation matrix of the data X , and let \tilde{C} be the regularized correlation matrix:

$$\tilde{C} = (1 - \gamma)C + \gamma I,$$

where I is the identity matrix.

The linear term in the regularized discriminant analysis classifier for a data point x is

$$(x - \mu_0)^T \tilde{\Sigma}^{-1} (\mu_k - \mu_0) = [(x - \mu_0)^T D^{-1/2}] [\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0)].$$

The parameter δ enters into this equation as a threshold on the final term in square brackets. Each component of the vector

$[\tilde{C}^{-1} D^{-1/2} (\mu_k - \mu_0)]$ is set to zero if it is smaller in magnitude than the threshold δ . Therefore, for class k , if component j is thresholded to zero, component j of x does not enter into the evaluation of the posterior probability.

The `DeltaPredictor` property is a vector related to this threshold. When $\delta \geq \text{DeltaPredictor}(i)$, all classes k have

$$|\tilde{C}^{-1}D^{-1/2}(\mu_k - \mu_0)| \leq \delta.$$

Therefore, when $\delta \geq \text{DeltaPredictor}(i)$, the regularized classifier does not use predictor i .

Examples

Find the Number of Nonzero Coefficients in a Discriminant Analysis Classifier

Find the number of nonzero coefficients in a discriminant analysis classifier for various `Delta` values.

Create a discriminant analysis classifier from the `fisheriris` data.

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
```

Find the number of nonzero coefficients in `obj`.

```
ncoeffs = nLinearCoeffs(obj)
```

```
ncoeffs =
```

```
4
```

Find the number of nonzero coefficients for `delta = 1, 2, 4, and 8`.

```
delta = [1 2 4 8];
ncoeffs = nLinearCoeffs(obj,delta)
```

```
ncoeffs =
```

```
4
```

```
4
```

```
3
```

```
0
```

The `DeltaPredictor` property gives the values of `delta` where the number of nonzero coefficients changes.

CompactClassificationDiscriminant.nLinearCoeffs

```
ncoeffs2 = nLinearCoeffs(obj,obj.DeltaPredictor)
```

```
ncoeffs2 =
```

```
4
```

```
3
```

```
1
```

```
2
```

See Also

[CompactClassificationDiscriminant | cvshrink | ClassificationDiscriminant.fit |](#)

Concepts

- “Discriminant Analysis” on page 12-3

Purpose

Nonlinear regression

Syntax

```
beta = nlinfit(X,Y,modelfun,beta0)
[beta,R,J,CovB,MSE] = nlinfit(X,Y,modelfun,beta0)
[ ___ ] = nlinfit(X,Y,modelfun,beta0,'Weights',W)

[ ___ ] = nlinfit(X,Y,modelfun,beta0,options)
[ ___ ] = nlinfit(X,Y,modelfun,beta0,options,'Weights',W)
```

Description

`beta = nlinfit(X,Y,modelfun,beta0)` returns a vector of estimated coefficients for the nonlinear regression of the responses in `Y` on the predictors in `X` using the model specified by `modelfun`. The coefficients are estimated using iterative least squares estimation, with initial values specified by `beta0`.

`[beta,R,J,CovB,MSE] = nlinfit(X,Y,modelfun,beta0)` additionally returns the residuals, `R`, the Jacobian of `modelfun`, `J`, the estimated variance-covariance matrix for the estimated coefficients, `CovB`, and an estimate of the variance of the error term, `MSE`.

`[___] = nlinfit(X,Y,modelfun,beta0,'Weights',W)` fits the nonlinear regression model using the observation weights, `W`. You can return any of the output arguments in the previous syntaxes. When you specify observation weights, output `R` is the weighted residuals, and output `J` is the weighted model function Jacobian.

`[___] = nlinfit(X,Y,modelfun,beta0,options)` fits the nonlinear regression using the algorithm control parameters in the structure `options`. You can return any of the output arguments in the previous syntaxes.

`[___] = nlinfit(X,Y,modelfun,beta0,options,'Weights',W)` uses observation weights, `W`.

Input Arguments

X - Predictor variables

matrix

Predictor variables for the nonlinear regression function, specified as a matrix. Typically, X is a design matrix of predictor (independent variable) values, with one row for each value in Y, and one column for each coefficient. However, X can be any array that `modelfun` can accept.

Data Types

single | double

Y - Response values

vector

Response values (dependent variable) for fitting the nonlinear regression function, specified as a vector with the same number of rows as X.

Data Types

single | double

modelfun - Nonlinear regression model function

function handle

Nonlinear regression model function, specified as a function handle. `modelfun` must accept two input arguments, a coefficient vector and an array X—in that order—and return a vector of fitted response values.

For example, to specify the `hougen` nonlinear regression function, use the function handle `@hougen`.

Data Types

function_handle

beta0 - Initial coefficient values

vector

Initial coefficient values for the least squares estimation algorithm, specified as a vector.

Note Poor starting values can lead to a solution with large residual error.

Data Types

single | double

W - Observation weights

vector | function handle

Observation weights, specified as a vector of real positive weights or a function handle. You can use observation weights to down-weight the observations that you want to have less influence on the fitted model.

Note `options.RobustWgtFun` must have value `[]` when you use observation weights.

- If `W` is a vector, then it must be the same size as `Y`.
- If `W` is a function handle, then it must accept a vector of predicted response values as input, and return a vector of real positive weights as output.

Data Types

double | single | function_handle

options - Estimation algorithm options

structure created using `statset`

Estimation algorithm options, specified as a structure you create using `statset`. The following `statset` parameters are applicable to `nlinfit`.

DerivStep - Relative difference for finite difference gradient

$\text{eps}^{1/3}$ (default) | positive scalar value | vector

Relative difference for the finite difference gradient calculation, specified as a positive scalar value, or a vector the same size as `beta`. Use a vector to specify a different relative difference for each coefficient.

Display - Level of output display

'off' (default) | 'iter' | 'final'

Level of output display during estimation, specified as one of 'off', 'iter', or 'final'. If you specify 'iter', output is displayed at each iteration. If you specify 'final', output is displayed after the final iteration.

FunValCheck - Indicator for whether to check for invalid values

'on' (default) | 'off'

Indicator for whether to check for invalid values such as NaN or Inf from the objective function, specified as 'on' or 'off'.

MaxIter - Maximum number of iterations

100 (default) | positive integer

Maximum number of iterations for the estimation algorithm, specified as a positive integer. Iterations continue until estimates are within the convergence tolerance, or the maximum number of iterations specified by `MaxIter` is reached.

RobustWgtFun - Weight function

string | function handle | []

Weight function for robust fitting, specified as a valid string or function handle.

Note `RobustWgtFun` must have value [] when you use observation weights, `W`.

The following table describes the possible string values. Let r denote normalized residuals and w denote robust weights. The indicator function $I[x]$ is equal to 1 if the expression x is true, and 0 otherwise.

Weight Function	Equation	Default Tuning Constant
' ' (default)	No robust fitting	—
'andrews'	$w = I[r < \pi] \times \sin(r) / r$	1.339
'bisquare'	$w = I[r < 1] \times (1 - r^2)^2$	4.685
'cauchy'	$w = \frac{1}{1 + r^2}$	2.385
'fair'	$w = \frac{1}{1 + r }$	1.400
'huber'	$w = \frac{1}{\max(1, r)}$	1.345
'logistic'	$w = \frac{\tanh(r)}{r}$	1.205

Weight Function	Equation	Default Tuning Constant
'talwar'	$w = I[r < 1]$	2.795
'welsch'	$w = \exp\{-r^2\}$	2.985

You can alternatively specify a function handle that accepts a vector of normalized residuals as input, and returns a vector of robust weights as output. If you use a function handle, you must provide a **Tune** constant.

Tune - Tuning constant

positive scalar value

Tuning constant for robust fitting, specified as a positive scalar value. The tuning constant is used to normalize residuals before applying a robust weight function. The default tuning constant depends on the function specified by **RobustWgtFun**.

If you use a function handle to specify **RobustWgtFun**, then you must specify a value for **Tune**.

TolFun - Termination tolerance on residual sum of squares

1e-8 (default) | positive scalar value

Termination tolerance for the residual sum of squares, specified as a positive scalar value. Iterations continue until estimates are within the convergence tolerance, or the maximum number of iterations specified by **MaxIter** is reached.

TolX - Termination tolerance on estimated coefficients

1e-8 (default) | positive scalar value

Termination tolerance on the estimated coefficients, **beta**, specified as a positive scalar value. Iterations continue until estimates are

within the convergence tolerance, or the maximum number of iterations specified by `MaxIter` is reached.

Robust - Indicator for robust fitting

'off' (default) | 'on'

Indicator for robust fitting, specified as 'off' or 'on'.

Note `Robust` will be removed in a future software release. Use `RobustWgtFun` for robust fitting.

WgtFun - Weight function for robust fitting

string | function handle

Weight function for robust fitting, specified as a string indicating a weight function, or a function handle. `WgtFun` is valid only when `Robust` has value 'on'.

Note `WgtFun` will be removed in a future software release. Use `RobustWgtFun` instead.

Output Arguments

beta - Estimated regression coefficients

vector

Estimated regression coefficients, returned as a vector. The number of elements in `beta` equals the number of elements in `beta0`.

Let $f(\mathbf{X}_i, \mathbf{b})$ denote the nonlinear function specified by `modelfun`, where \mathbf{x}_i are the predictors for observation i , $i = 1, \dots, N$, and \mathbf{b} are the regression coefficients. The vector of coefficients returned in `beta` minimizes the weighted least squares equation,

$$\sum_{i=1}^N w_i [y_i - f(\mathbf{x}_i, \mathbf{b})]^2.$$

For unweighted nonlinear regression, all of the weight terms are equal to 1.

R - Residuals

vector

Residuals for the fitted model, returned as a vector. If you specify observation weights, *W*, then *R* contains weighted residuals.

J - Jacobian

matrix

Jacobian of the nonlinear regression model, `modelfun`, returned as an *N*-by-*p* matrix, where *N* is the number of observations and *p* is the number of estimated coefficients. If you specify observation weights, *W*, then *J* is the weighted model function Jacobian.

CovB - Estimated variance-covariance matrix

matrix

Estimated variance-covariance matrix for the fitted coefficients, `beta`, returned as a *p*-by-*p* matrix, where *p* is the number of estimated coefficients. If the model Jacobian, *J*, has full column rank, then $\text{CovB} = \text{inv}(J' * J) * \text{MSE}$, where *MSE* is the mean squared error.

MSE - Mean squared error

scalar value

Mean squared error (MSE) of the fitted model, returned as a scalar value. *MSE* is an estimate of the variance of the error term. If the model Jacobian, *J*, has full column rank, then $\text{MSE} = (R' * R) / (N - p)$, where *N* is the number of observations, and *p* is the number of estimated coefficients.

Examples

Fit Nonlinear Regression Model

Load sample data.

```
S = load('reaction');
```

```
X = S.reactants;
y = S.rate;
beta0 = S.beta;
```

Fit the Hougen-Watson model to the rate data using the initial values in beta0.

```
beta = nlinfit(X,y,@hougen,beta0)
```

```
beta =

    1.2526
    0.0628
    0.0400
    0.1124
    1.1914
```

Fit Nonlinear Regression Model Using Robust Options

Generate sample data from the nonlinear regression model

$$y = b_1 + b_2 \exp\{-b_3 x\} + \varepsilon,$$

where b_1 , b_2 , and b_3 are coefficients, and the error term is normally distributed with mean 0 and standard deviation 0.1.

```
modelfun = @(b,x)(b(1)+b(2)*exp(-b(3)*x));
```

```
rng('default') % for reproducibility
b = [1;3;2];
x = exprnd(2,100,1);
y = modelfun(b,x) + normrnd(0,0.1,100,1);
```

Set robust fitting options.

```
opts = statset('nlinfit');
opts.RobustWgtFun = 'bisquare';
```

Fit the nonlinear model using the robust fitting options.

```
beta0 = [2;2;2];  
beta = nlinfit(x,y,modelfun,beta0,opts)
```

```
beta =  
  
    1.0041  
    3.0997  
    2.1483
```

Fit Nonlinear Regression Model Using Observation Weights

Load sample data.

```
S = load('reaction');  
X = S.reactants;  
y = S.rate;  
beta0 = S.beta;
```

Specify a vector of known observation weights.

```
W = [8 2 1 6 12 9 12 10 10 12 2 10 8]';
```

Fit the Hougen-Watson model to the rate data using the specified observation weights.

```
[beta,R,J,CovB] = nlinfit(X,y,@hougen,beta0,'Weights',W);
```

```
beta
```

```
beta =  
  
    2.2068  
    0.1077  
    0.0766  
    0.1818  
    0.6516
```

Display the coefficient standard errors.


```
sqrt(diag(CovB))
```

```
ans =
```

```
    2.5721  
    0.1251  
    0.0950  
    0.2043  
    0.7735
```

Fit Nonlinear Regression Model Using Weights Function Handle

Load sample data.

```
S = load('reaction');  
X = S.reactants;  
y = S.rate;  
beta0 = S.beta;
```

Specify a function handle for observation weights. The function accepts the model fitted values as input, and returns a vector of weights.

```
a = 1; b = 1;  
weights = @(yhat) 1./((a + b*abs(yhat)).^2);
```

Fit the Hougen-Watson model to the rate data using the specified observation weights function.

```
[beta,R,J,CovB] = nlinfit(X,y,@hougen,beta0,'Weights',weights);
```

```
beta
```

```
beta =
```

```
    0.8308  
    0.0409  
    0.0251  
    0.0801
```

```
1.8261
```

Display the coefficient standard errors.

```
sqrt(diag(CovB))
```

```
ans =
```

```
0.5822
```

```
0.0297
```

```
0.0197
```

```
0.0578
```

```
1.2810
```

Tips

- To produce error estimates on predictions, use the optional output arguments `R`, `J`, `CovB`, or `MSE` as inputs to `nlpredci`.
- To produce error estimates on the estimated coefficients, `beta`, use the optional output arguments `R`, `J`, `CovB`, or `MSE` as inputs to `nlparci`.
- If you use the robust fitting option, `RobustWgtFun`, you must use `CovB`—and might need `MSE`—as inputs to `nlpredci` or `nlparci` to ensure that the confidence intervals take the robust fit properly into account.

Algorithms

- `nlinfit` treats NaN values in `Y` or `modelfun(beta0,X)` as missing data, and ignores the corresponding observations.
- For nonrobust estimation, `nlinfit` uses the Levenberg-Marquardt nonlinear least squares algorithm [1].
- For robust estimation, `nlinfit` uses an iterative reweighted least squares algorithm ([2], [3]). At each iteration, the robust weights are recalculated based on each observation's residual from the previous iteration. These weights downweight outliers, so that their influence on the fit is decreased. Iterations continue until the weights converge.
- When you specify a function handle for observation weights, the weights depend on the fitted model. In this case, `nlinfit` uses an

iterative generalized least squares algorithm to fit the nonlinear regression model.

Definitions **Weighted Residuals**

A *weighted residual* is a residual multiplied by the square root of the corresponding observation weight.

Given estimated regression coefficients, \mathbf{b} , the residual for observation i is

$$r_i = y_i - f(\mathbf{x}_i, \mathbf{b}),$$

where y_i is the observed response and $f(\mathbf{x}_i, \mathbf{b})$ is the fitted response at predictors \mathbf{x}_i .

When you fit a weighted nonlinear regression with weights w_i , $i = 1, \dots, N$, `nlinfit` returns the weighted residuals,

$$r_i^* = \sqrt{w_i} (y_i - f(\mathbf{x}_i, \mathbf{b})).$$

Weighted Model Function Jacobian

The *weighted model function Jacobian* is the nonlinear model Jacobian multiplied by the square root of the observation weight matrix.

Given estimated regression coefficients, \mathbf{b} , the estimated model Jacobian, \mathbf{J} , for the nonlinear function $f(\mathbf{x}_i, \mathbf{b})$ has elements

$$\mathbf{J}_{ij} = \frac{\partial f(\mathbf{x}_i, \mathbf{b})}{\partial b_j},$$

where b_j is the j th element of \mathbf{b} .

When you fit a weighted nonlinear regression with diagonal weights matrix \mathbf{W} , `nlinfit` returns the weighted Jacobian matrix,

$$\mathbf{J}^* = \mathbf{W}^{1/2} \mathbf{J}.$$

References

[1] Seber, G. A. F., and C. J. Wild. *Nonlinear Regression*. Hoboken, NJ: Wiley-Interscience, 2003.

[2] DuMouchel, W. H., and F. L. O'Brien. "Integrating a Robust Option into a Multiple Regression Computing Environment." *Computer Science and Statistics: Proceedings of the 21st Symposium on the Interface*. Alexandria, VA: American Statistical Association, 1989.

[3] Holland, P. W., and R. E. Welsch. "Robust Regression Using Iteratively Reweighted Least-Squares." *Communications in Statistics: Theory and Methods*, A6, 1977, pp. 813–827.

See Also

`NonLinearModel.fit` | `nlparci` | `nlpredci` | `nlintool`

Concepts

- "Nonlinear Regression" on page 9-196

Purpose

Interactive nonlinear regression

Syntax

```
nlintool(X,y,fun,beta0)
nlintool(X,y,fun,beta0,alpha)
nlintool(X,y,fun,beta0,alpha,'xname','yname')
```

Description

`nlintool(X,y,fun,beta0)` is a graphical user interface to the `nlinfit` function, and uses the same input arguments. The interface displays plots of the fitted response against each predictor, with the other predictors held fixed. The fixed values are in the text boxes below each predictor axis. Change the fixed values by typing in a new value or by dragging the vertical lines in the plots to new positions. When you change the value of a predictor, all plots update to display the model at the new point in predictor space. Dashed red curves show 95% simultaneous confidence bands for the function.

`nlintool(X,y,fun,beta0,alpha)` shows $100(1-\alpha)\%$ confidence bands. These are simultaneous confidence bounds for the function value. Using the **Bounds** menu you can switch between simultaneous and non-simultaneous bounds, and between bounds on the function and bounds for predicting a new observation.

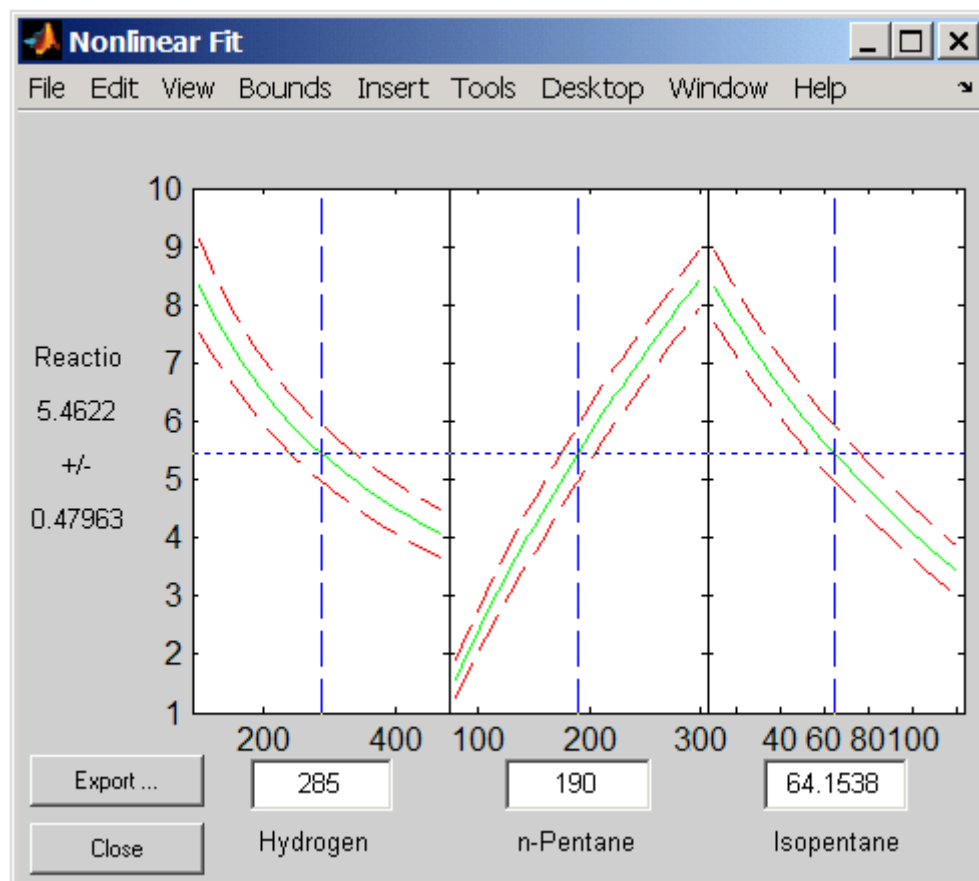
`nlintool(X,y,fun,beta0,alpha,'xname','yname')` labels the plots using the string matrix `'xname'` for the predictors and the string `'yname'` for the response.

Examples

The data in `reaction.mat` are partial pressures of three chemical reactants and the corresponding reaction rates. The function `hougen` implements the nonlinear Hougen-Watson model for reaction rates. The following fits the model to the data:

```
load reaction
nlintool(reactants,rate,@hougen,beta,0.01,xn,yn)
```

nlintool



See Also

[nlinfit](#) | [polytool](#) | [rstool](#)

Purpose

Nonlinear mixed-effects estimation

Syntax

```
beta = nlmefit(X,y,group,V,fun,beta0)
[beta,PSI] = nlmefit(X,y,group,V,fun,beta0)
[beta,PSI,stats] = nlmefit(X,y,group,V,fun,beta0)
[beta,PSI,stats,B] = nlmefit(X,y,group,V,fun,beta0)
[beta,PSI,stats,B] = nlmefit(X,y,group,V,fun,beta0,'Name',
    value)
```

Description

`beta = nlmefit(X,y,group,V,fun,beta0)` fits a nonlinear mixed-effects regression model and returns estimates of the fixed effects in `beta`. By default, `nlmefit` fits a model in which each parameter is the sum of a fixed and a random effect, and the random effects are uncorrelated (their covariance matrix is diagonal).

`X` is an n -by- h matrix of n observations on h predictors.

`y` is an n -by-1 vector of responses.

`group` is a grouping variable indicating m groups in the observations. `group` is a categorical variable, a numeric vector, a character matrix with rows for group names, or a cell array of strings. For more information on grouping variables, see “Grouping Variables” on page 2-72.

`V` is an m -by- g matrix or cell array of g group-specific predictors. These are predictors that take the same value for all observations in a group. The rows of `V` are assigned to groups using `grp2idx`, according to the order specified by `grp2idx(group)`. Use a cell array for `V` if group predictors vary in size across groups. Use `[]` for `V` if there are no group-specific predictors.

`fun` is a handle to a function that accepts predictor values and model parameters and returns fitted values. `fun` has the form

```
yfit = modelfun(PHI,XFUN,VFUN)
```

The arguments are:

- `PHI` — A 1-by- p vector of model parameters.

- XFUN — A k -by- h array of predictors, where:
 - $k = 1$ if XFUN is a single row of X.
 - $k = n_i$ if XFUN contains the rows of X for a single group of size n_i .
 - $k = n$ if XFUN contains all rows of X.
- VFUN — Group-specific predictors given by one of:
 - A 1-by- g vector corresponding to a single group and a single row of V.
 - An n -by- g array, where the j th row is $V(I,:)$ if the j th observation is in group I.

If V is empty, nlmefit calls modelfun with only two inputs.

- yfit — A k -by-1 vector of fitted values

When either PHI or VFUN contains a single row, it corresponds to all rows in the other two input arguments.

Note If modelfun can compute yfit for more than one vector of model parameters per call, use the 'Vectorization' parameter (described later) for improved performance.

beta0 is a q -by-1 vector with initial estimates for q fixed effects. By default, q is the number of model parameters p .

nlmefit fits the model by maximizing an approximation to the marginal likelihood with random effects integrated out, assuming that:

- Random effects are multivariate normally distributed and independent between groups.
- Observation errors are independent, identically normally distributed, and independent of the random effects.

`[beta,PSI] = nlmefit(X,y,group,V,fun,beta0)` also returns `PSI`, an r -by- r estimated covariance matrix for the random effects. By default, r is equal to the number of model parameters p .

`[beta,PSI,stats] = nlmefit(X,y,group,V,fun,beta0)` also returns `stats`, a structure with fields:

- `dfe` — The error degrees of freedom for the model
- `logl` — The maximized loglikelihood for the fitted model
- `rmse` — The square root of the estimated error variance (computed on the log scale for the exponential error model)
- `errorparam` — The estimated parameters of the error variance model
- `aic` — The Akaike information criterion, calculated as $\text{aic} = -2 * \text{logl} + 2 * \text{numParam}$, where `numParam` is the number of fitting parameters, including the degree of freedom for covariance matrix of the random effects, the number of fixed effects and the number of parameters of the error model, and `logl` is a field in the `stats` structure
- `bic` — The Bayesian information criterion, calculated as $\text{bic} = -2 * \text{logl} + \log(M) * \text{numParam}$
 - `M` is the number of groups.
 - `numParam` and `logl` are defined as in `aic`.

Note that some literature suggests that the computation of `bic` should be , $\text{bic} = -2 * \text{logl} + \log(N) * \text{numParam}$, where `N` is the number of observations.
- `covb` — The estimated covariance matrix of the parameter estimates
- `sebeta` — The standard errors for `beta`
- `ires` — The population residuals ($y - y_{\text{population}}$), where `y_population` is the individual predicted values
- `pres` — The population residuals ($y - y_{\text{population}}$), where `y_population` is the population predicted values
- `iwres` — The individual weighted residuals

- `pwres` — The population weighted residuals
- `cwres` — The conditional weighted residuals

`[beta,PSI,stats,B] = nlmefit(X,y,group,V,fun,beta0)` also returns `B`, an r -by- m matrix of estimated random effects for the m groups. By default, r is equal to the number of model parameters p .

`[beta,PSI,stats,B] = nlmefit(X,y,group,V,fun,beta0,'Name',value)` specifies one or more optional parameter name/value pairs. Specify *Name* inside single quotes.

Use the following parameters to fit a model different from the default. (The default model is obtained by setting both `FEConstDesign` and `REConstDesign` to `eye(p)`, or by setting both `FEPARAMSSelect` and `REPARAMSSelect` to `1:p`.) Use at most one parameter with an 'FE' prefix and one parameter with an 'RE' prefix. The `nlmefit` function requires you to specify at least one fixed effect and one random effect.

Parameter	Value
<code>FEPARAMSSelect</code>	A vector specifying which elements of the parameter vector <code>PHI</code> include a fixed effect, given as a numeric vector of indices from 1 to p or as a 1-by- p logical vector. If q is the specified number of elements, then the model includes q fixed effects.
<code>FEConstDesign</code>	A p -by- q design matrix <code>ADESIGN</code> , where <code>ADESIGN*beta</code> are the fixed components of the p elements of <code>PHI</code> .
<code>FEGROUPDesign</code>	A p -by- q -by- m array specifying a different p -by- q fixed-effects design matrix for each of the m groups.
<code>FEObsDesign</code>	A p -by- q -by- n array specifying a different p -by- q fixed-effects design matrix for each of the n observations.

Parameter	Value
REParamsSelect	A vector specifying which elements of the parameter vector PHI include a random effect, given as a numeric vector of indices from 1 to p or as a 1-by- p logical vector. The model includes r random effects, where r is the specified number of elements.
REConstDesign	A p -by- r design matrix BDESIGN, where BDESIGN*B are the random components of the p elements of PHI.
REGroupDesign	A p -by- r -by- m array specifying a different p -by- r random-effects design matrix for each of m groups.
REObsDesign	A p -by- r -by- n array specifying a different p -by- r random-effects design matrix for each of n observations.

Use the following parameters to control the iterative algorithm for maximizing the likelihood:

Parameter	Value
RefineBeta0	Determines whether nlmefit makes an initial refinement of beta0 by first fitting modelfun without random effects and replacing beta0 with beta. Choices are 'on' and 'off'. The default value is 'on'.
ErrorModel	A string specifying the form of the error term. Default is 'constant'. Each model defines the error using a standard normal (Gaussian) variable e , the function value f , and one or two parameters a and b . Choices are: <ul style="list-style-type: none"> 'constant': $y = f + a*e$

Parameter	Value
	<ul style="list-style-type: none"> • 'proportional': $y = f + b \cdot f^a \cdot e$ • 'combined': $y = f + (a + b \cdot f)^a \cdot e$ • 'exponential': $y = f \cdot \exp(a \cdot e)$, or equivalently $\log(y) = \log(f) + a \cdot e$ <p>If this parameter is given, the output <code>stats.errorparam</code> field has the value</p> <ul style="list-style-type: none"> • a for 'constant' and 'exponential' • b for 'proportional' • $[a \ b]$ for 'combined'
ApproximationType	<p>The method used to approximate the likelihood of the model. Choices are:</p> <ul style="list-style-type: none"> • 'LME' — Use the likelihood for the linear mixed-effects model at the current conditional estimates of <code>beta</code> and <code>B</code>. This is the default. • 'RELME' — Use the restricted likelihood for the linear mixed-effects model at the current conditional estimates of <code>beta</code> and <code>B</code>. • 'FO' — First-order Laplacian approximation without random effects. • 'FOCE' — First-order Laplacian approximation at the conditional estimates of <code>B</code>.

Parameter	Value
Vectorization	<p>Indicates acceptable sizes for the PHI, XFUN, and VFUN input arguments to <code>modelfun</code>. Choices are:</p> <ul style="list-style-type: none">• 'SinglePhi' — <code>modelfun</code> can only accept a single set of model parameters at a time, so PHI must be a single row vector in each call. <code>nlmefit</code> calls <code>modelfun</code> in a loop, if necessary, with a single PHI vector and with XFUN containing rows for a single observation or group at a time. VFUN may be a single row that applies to all rows of XFUN, or a matrix with rows corresponding to rows in XFUN. This is the default.• 'SingleGroup' — <code>modelfun</code> can only accept inputs corresponding to a single group in the data, so XFUN must contain rows of X from a single group in each call. Depending on the model, PHI is a single row that applies to the entire group or a matrix with one row for each observation. VFUN is a single row.• 'Full' — <code>modelfun</code> can accept inputs for multiple parameter vectors and multiple groups in the data. Either PHI or VFUN may be a single row that applies to all rows of XFUN or a matrix with rows corresponding to rows in XFUN. This option can improve performance by reducing the number of calls to <code>modelfun</code>, but may require <code>modelfun</code> to perform singleton expansion on PHI or V.

Parameter	Value
CovParameterization	Specifies the parameterization used internally for the scaled covariance matrix. Choices are 'chol' for the Cholesky factorization or 'logm' the matrix logarithm. The default is 'logm'.
CovPattern	<p>Specifies an r-by-r logical or numeric matrix P that defines the pattern of the random-effects covariance matrix Ψ. <code>nlmefit</code> estimates the variances along the diagonal of Ψ and the covariances specified by nonzeros in the off-diagonal elements of P. Covariances corresponding to zero off-diagonal elements in P are constrained to be zero. If P does not specify a row-column permutation of a block diagonal matrix, <code>nlmefit</code> adds nonzero elements to P as needed. The default value of P is $\text{eye}(r)$, corresponding to uncorrelated random effects.</p> <p>Alternatively, P may be a 1-by-r vector containing values in $1:r$, with equal values specifying groups of random effects. In this case, <code>nlmefit</code> estimates covariances only within groups, and constrains covariances across groups to be zero.</p>

Parameter	Value
ParamTransform	<p>A vector of p-values specifying a transformation function $f()$ for each of the P parameters: $XB = ADESIGN*BETA + BDESIGN*B$ $PHI = f(XB)$. Each element of the vector must be one of the following integer codes specifying the transformation for the corresponding value of PHI:</p> <ul style="list-style-type: none"> • 0: $PHI = XB$ (default for all parameters) • 1: $\log(PHI) = XB$ • 2: $\text{probit}(PHI) = XB$ • 3: $\text{logit}(PHI) = XB$
Options	<p>A structure of the form returned by <code>statset</code>. <code>nlmefit</code> uses the following <code>statset</code> parameters:</p> <ul style="list-style-type: none"> • 'DerivStep' — Relative difference used in finite difference gradient calculation. May be a scalar, or a vector whose length is the number of model parameters p. The default is $\text{eps}^{(1/3)}$. • 'Display' — Level of iterative display during estimation. Choices are: <ul style="list-style-type: none"> ▪ 'off' (default) — Displays no information ▪ 'final' — Displays information after the final iteration ▪ 'iter' — Displays information at each iteration • 'FunValCheck' — Check for invalid values, such as NaN or Inf, from

Parameter	Value
	<p>modelfun. Choices are 'on' and 'off'. The default is 'on'.</p> <ul style="list-style-type: none"> 'MaxIter' — Maximum number of iterations allowed. The default is 200. 'OutputFcn' — Function handle specified using @, a cell array with function handles or an empty array (default). The solver calls all output functions after each iteration. 'TolFun' — Termination tolerance on the loglikelihood function. The default is 1e-4. 'TolX' — Termination tolerance on the estimated fixed and random effects. The default is 1e-4.
OptimFun	<p>Specifies the optimization function used in maximizing the likelihood. Choices are 'fminsearch' to use fminsearch or 'fminunc' to use fminunc. The default is 'fminsearch'. You can specify 'fminunc' only if Optimization Toolbox software is installed.</p>

Examples

Display data on the growth of five orange trees:

```
CIRC = [30 58 87 115 120 142 145;
        33 69 111 156 172 203 203;
        30 51 75 108 115 139 140;
        32 62 112 167 179 209 214;
        30 49 81 125 142 174 177];
time = [118 484 664 1004 1231 1372 1582];

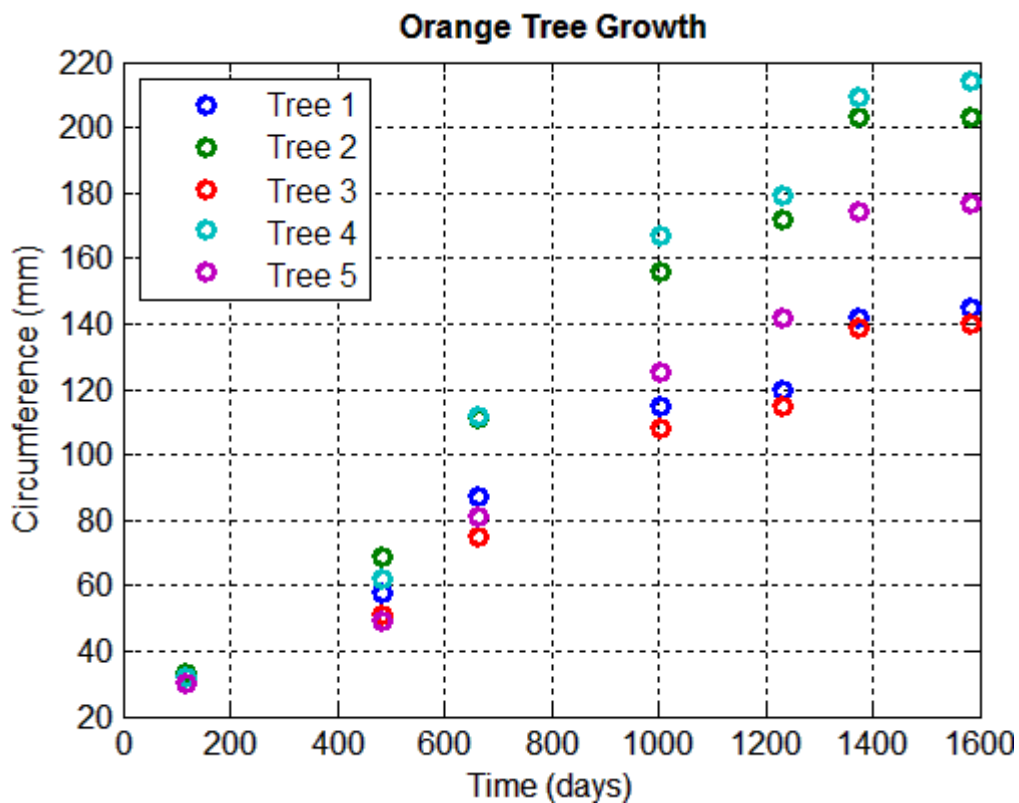
h = plot(time,CIRC,'o','LineWidth',2);
```



```

xlabel('Time (days)')
ylabel('Circumference (mm)')
title('\bf Orange Tree Growth')
legend([repmat('Tree ',5,1),num2str((1:5)')],...
       'Location','NW')
grid on
hold on

```



Use an anonymous function to specify a logistic growth model:

```
model=@(PHI,t)(PHI(:,1))./(1+exp(-(t-PHI(:,2))./PHI(:,3)));
```

Fit the model using `nlmefit` with default settings (that is, assuming each parameter is the sum of a fixed and a random effect, with no correlation among the random effects):

```
TIME = repmat(time,5,1);
NUMS = repmat((1:5)',size(time));

beta0 = [100 100 100];
[beta1,PSI1,stats1] = nlmefit(TIME(:),CIRC(:),NUMS(:),...
                             [],model,beta0)

beta1 =
    191.3189
    723.7608
    346.2517

PSI1 =
    962.1534         0         0
         0    0.0000         0
         0         0    297.9881

stats1 =
    dfe: 28
    logl: -131.5457
    mse: 59.7882
    rmse: 7.9016
    errorparam: 7.7323
    aic: 277.0913
    bic: 274.3574
    covb: [3x3 double]
    sebeta: [15.2249 33.1579 26.8235]
    ires: [35x1 double]
    pres: [35x1 double]
    iwres: [35x1 double]
    pwres: [35x1 double]
    cwres: [35x1 double]
```

The negligible variance of the second random effect, PSI1(2,2), suggests that it can be removed to simplify the model:

```
[beta2,PSI2,stats2,b2] = nlmefit(TIME(:),CIRC(:),...  
    NUMS(:),[],model,beta0,'REParamsSelect',[1 3])
```

```
beta2 =
```

```
191.3194  
723.7628  
346.2548
```

```
PSI2 =
```

```
962.2114      0  
0 298.3989
```

```
stats2 =
```

```
    dfe: 29  
    logl: -131.5456  
    mse: 59.7851  
    rmse: 7.7640  
    errorparam: 7.7321  
    aic: 275.0913  
    bic: 272.7479  
    covb: [3x3 double]  
    sebeta: [15.2252 33.1572 26.8246]  
    ires: [35x1 double]  
    pres: [35x1 double]  
    iwres: [35x1 double]  
    pwres: [35x1 double]  
    cwres: [35x1 double]
```

```
b2 =
```

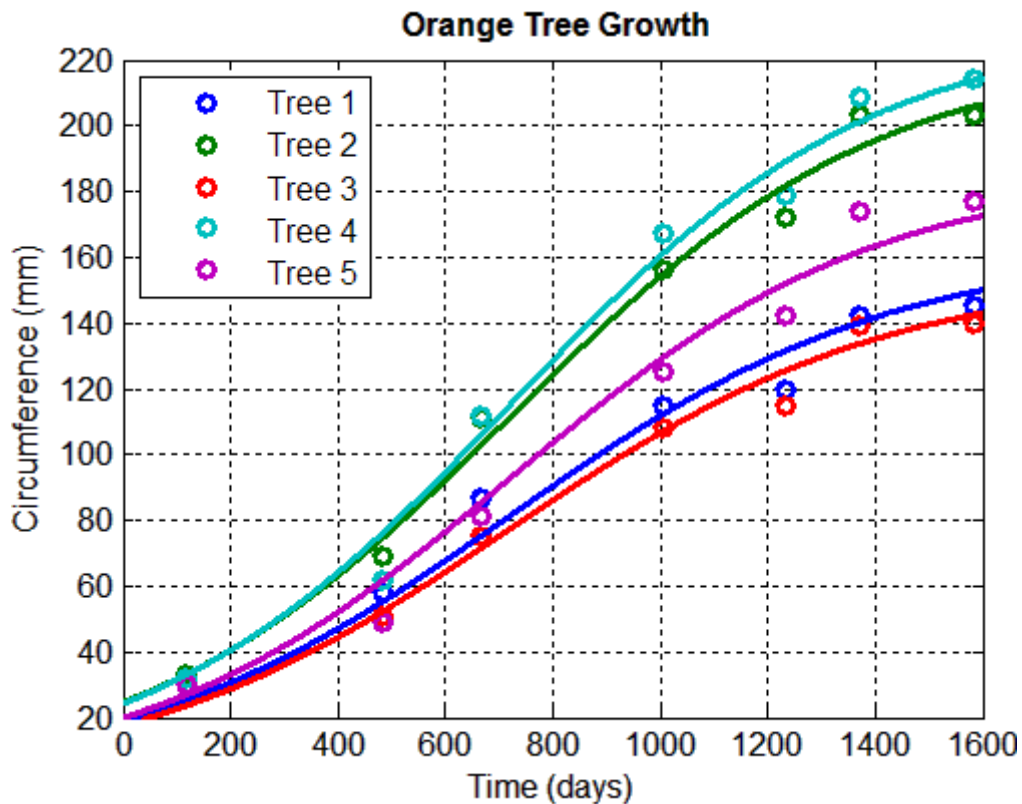
```
-28.5250    31.6063   -36.5070    39.0735   -5.6479  
10.0097   -0.7638     6.0117   -9.4685   -5.7892
```

The loglikelihood `logl` is unaffected, and both the Akaike and Bayesian information criteria (`aic` and `bic`) are reduced, supporting the decision to drop the second random effect from the model.

Use the estimated fixed effects in `beta2` and the estimated random effects for each tree in `b2` to plot the model through the data:

```
PHI = repmat(beta2,1,5) + ...           % Fixed effects
      [b2(1,:);zeros(1,5);b2(2,:)];    % Random effects

colors = get(h,'Color');
tplot = 0:0.1:1600;
for I = 1:5
    fitted_model=@(t)(PHI(1,I))./(1+exp(-(t-PHI(2,I))./ ...
    PHI(3,I)));
    plot(tplot,fitted_model(tplot),'Color',colors{I}, ...
        'LineWidth',2)
end
```



References

- [1] Lindstrom, M. J., and D. M. Bates. "Nonlinear mixed-effects models for repeated measures data." *Biometrics*. Vol. 46, 1990, pp. 673–687.
- [2] Davidian, M., and D. M. Giltinan. *Nonlinear Models for Repeated Measurements Data*. New York: Chapman & Hall, 1995.
- [3] Pinheiro, J. C., and D. M. Bates. "Approximations to the log-likelihood function in the nonlinear mixed-effects model." *Journal of Computational and Graphical Statistics*. Vol. 4, 1995, pp. 12–35.

[4] Demidenko, E. *Mixed Models: Theory and Applications*. Hoboken, NJ: John Wiley & Sons, Inc., 2004.

See Also

`nlinfit` | `nlpredci` | `nlmefitsa`

How To

- “Mixed-Effects Models” on page 9-217
- “Grouping Variables” on page 2-72

Purpose

Fit nonlinear mixed-effects model with stochastic EM algorithm

Syntax

```
[BETA,PSI,STATS,B] = nlmefitsa(X,Y,GROUP,V,MODELFUN,BETA0)
[BETA,PSI,STATS,B] = nlmefitsa(X,Y,GROUP,V,MODELFUN,BETA0,
    'Name',Value)
```

Description

[BETA,PSI,STATS,B] = nlmefitsa(X,Y,GROUP,V,MODELFUN,BETA0) fits a nonlinear mixed-effects regression model and returns estimates of the fixed effects in BETA. By default, nlmefitsa fits a model where each model parameter is the sum of a corresponding fixed and random effect, and the covariance matrix of the random effects is diagonal, i.e., uncorrelated random effects.

The BETA, PSI, and other values this function returns are the result of a random (Monte Carlo) simulation designed to converge to the maximum likelihood estimates of the parameters. Because the results are random, it is advisable to examine the plot of simulation to results to be sure that the simulation has converged. It may also be helpful to run the function multiple times, using multiple starting values, or use the 'Replicates' parameter to perform multiple simulations.

[BETA,PSI,STATS,B] = nlmefitsa(X,Y,GROUP,V,MODELFUN,BETA0,'Name',Value) accepts one or more comma-separated parameter name/value pairs. Specify *Name* inside single quotes.

Input Arguments**Definitions:**

In the following list of arguments, the following variable definitions apply:

- *n* — number of observations
- *h* — number of predictor variables
- *m* — number of groups
- *g* — number of group-specific predictor variables
- *p* — number of parameters

- f — number of fixed effects

X

An n -by- h matrix of n observations on h predictor variables.

Y

An n -by-1 vector of responses.

GROUP

A grouping variable indicating to which of m groups each observation belongs. **GROUP** can be a categorical variable, a numeric vector, a character matrix with rows for group names, or a cell array of strings.

V

An m -by- g matrix of g group-specific predictor variables for each of the m groups in the data. These are predictor values that take on the same value for all observations in a group. Rows of **V** are ordered according to `GRP2IDX(GROUP)`. Use an m -by- g cell array for **V** if any of the group-specific predictor values vary in size across groups. Specify `[]` for **V** if there are no group predictors.

MODELFUN

A handle to a function that accepts predictor values and model parameters, and returns fitted values. **MODELFUN** has the form `YFIT = MODELFUN(PHI, XFUN, VFUN)` with input arguments

- **PHI** — A 1-by- p vector of model parameters.
- **XFUN** — An l -by- h array of predictor variables where
 - l is 1 if **XFUN** is a single row of **X**
 - l is n_i if **XFUN** contains the rows of **X** for a single group of size n_i
 - l is n if **XFUN** contains all rows of **X**.
- **VFUN** — Either

- A 1-by- g vector of group-specific predictors for a single group, corresponding to a single row of V
- An n -by- g matrix, where the k -th row of $VFUN$ is $V(i,:)$ if the k -th observation is in group i .

If V is empty, `nlmefitsa` calls `MODELFUN` with only two inputs.

`MODELFUN` returns an l -by-1 vector of fitted values `YFIT`. When either `PHI` or `VFUN` contains a single row, that one row corresponds to all rows in the other two input arguments. For improved performance, use the 'Vectorization' parameter name/value pair (described below) if `MODELFUN` can compute `YFIT` for more than one vector of model parameters in one call.

BETA0

An f -by-1 vector with initial estimates for the f fixed effects. By default, f is equal to the number of model parameters p . `BETA0` can also be an f -by-`REPS` matrix, and the estimation is repeated `REPS` times using each column of `BETA0` as a set of starting values.

Name-Value Pair Arguments

By default, `nlmefitsa` fits a model where each model parameter is the sum of a corresponding fixed and random effect. Use the following parameter name/value pairs to fit a model with a different number of or dependence on fixed or random effects. Use at most one parameter name with an 'FE' prefix and one parameter name with an 'RE' prefix. Note that some choices change the way `nlmefitsa` calls `MODELFUN`, as described further below.

FEParamsSelect

A vector specifying which elements of the model parameter vector `PHI` include a fixed effect, as a numeric vector with elements in $1:p$, or as a 1-by- p logical vector. The model will include f fixed effects, where f is the specified number of elements.

FEConstDesign

A p -by- f design matrix `ADESIGN`, where `ADESIGN*BETA` are the fixed components of the p elements of `PHI`.

FEGroupDesign

A p -by- f -by- m array specifying a different p -by- f fixed effects design matrix for each of the m groups.

REParamsSelect

A vector specifying which elements of the model parameter vector `PHI` include a random effect, as a numeric vector with elements in $1:p$, or as a 1-by- p logical vector. The model will include r random effects, where r is the specified number of elements.

REConstDesign

A p -by- r design matrix `BDESIGN`, where `BDESIGN*B` are the random components of the p elements of `PHI`. This matrix must consist of 0s and 1s, with at most one 1 per row.

The default model is equivalent to setting both `FEConstDesign` and `REConstDesign` to `eye(p)`, or to setting both `FEParamsSelect` and `REParamsSelect` to $1:p$.

Additional optional parameter name/value pairs control the iterative algorithm used to maximize the likelihood:

CovPattern

Specifies an r -by- r logical or numeric matrix `PAT` that defines the pattern of the random effects covariance matrix `PSI`. `nlmefitsa` computes estimates for the variances along the diagonal of `PSI` as well as covariances that correspond to non-zeroes in the off-diagonal of `PAT`. `nlmefitsa` constrains the remaining covariances, i.e., those corresponding to off-diagonal zeroes in `PAT`, to be zero. `PAT` must be a row-column permutation of a block diagonal matrix, and `nlmefitsa` adds non-zero elements to `PAT` as needed to produce such a pattern. The

default value of PAT is $\text{eye}(r)$, corresponding to uncorrelated random effects.

Alternatively, specify PAT as a 1-by- r vector containing values in 1: r . In this case, elements of PAT with equal values define groups of random effects, nlmefitsa estimates covariances only within groups, and constrains covariances across groups to be zero.

Cov0

Initial value for the covariance matrix PSI. Must be an r -by- r positive definite matrix. If empty, the default value depends on the values of BETA0.

ComputeStdErrors

true to compute standard errors for the coefficient estimates and store them in the output STATS structure, or false (default) to omit this computation.

ErrorModel

A string specifying the form of the error term. Default is 'constant'. Each model defines the error using a standard normal (Gaussian) variable e , the function value f , and one or two parameters a and b . Choices are

- 'constant' — $y = f + a*e$
- 'proportional' — $y = f + b*f*e$
- 'combined' — $y = f + (a+b*f)*e$
- 'exponential' — $y = f*\exp(a*e)$, or equivalently $\log(y) = \log(f) + a*e$

If this parameter is given, the output STATS.rmse field has the value

- a for 'constant' and 'exponential'
- b for 'proportional'
- $[a \ b]$ for 'combined'

ErrorParameters

A scalar or two-element vector specifying starting values for parameters of the error model. This specifies the a , b , or $[a\ b]$ values depending on the `ErrorModel` parameter.

LogLikMethod

Specifies the method for approximating the loglikelihood. Choices are:

- 'is' — Importance sampling
- 'gq' — Gaussian quadrature
- 'lin' — Linearization
- 'none' — Omit the loglikelihood approximation (default)

NBurnIn

Number of initial burn-in iterations during which the parameter estimates are not recomputed. Default is 5.

NChains

Number c of "chains" simulated. Default is 1. Setting $c > 1$ causes c simulated coefficient vectors to be computed for each group during each iteration. Default depends on the data, and is chosen to provide about 100 groups across all chains.

NIterations

Number of iterations. This can be a scalar or a three-element vector. Controls how many iterations are performed for each of three phases of the algorithm:

- 1** simulated annealing
- 2** full step size
- 3** reduced step size

Default is [150 150 100]. A scalar is distributed across the three phases in the same proportions as the default.

NMCMCIterations

Number of Markov Chain Monte Carlo (MCMC) iterations. This can be a scalar or a three-element vector. Controls how many of three different types of MCMC updates are performed during each phase of the main iteration:

- 1** full multivariate update
- 2** single coordinate update
- 3** multiple coordinate update

Default is [2 2 2]. A scalar value is treated as a three-element vector with all elements equal to the scalar.

OptimFun

Either 'fminsearch' or 'fminunc', specifying the optimization function to be used during the estimation process. Default is 'fminsearch'. Use of 'fminunc' requires Optimization Toolbox.

Options

A structure created by a call to `statset`. `nlmefitsa` uses the following `statset` parameters:

- 'DerivStep' — Relative difference used in finite difference gradient calculation. May be a scalar, or a vector whose length is the number of model parameters p . The default is $\text{eps}^{(1/3)}$.
- Display — Level of display during estimation.
 - 'off' (default) — Displays no information
 - 'final' — Displays information after the final iteration of the estimation algorithm

- 'iter' — Displays information at each iteration
- FunValCheck
 - 'on' (sdefault) — Check for invalid values (such as NaN or Inf) from MODELFUN
 - 'off' — Skip this check
- OutputFcn — Function handle specified using @, a cell array with function handles or an empty array. nlmefitsa calls all output functions after each iteration. See nlmefitoutputfcn.m (the default output function for nlmefitsa) for an example of an output function.

ParamTransform

A vector of p -values specifying a transformation function $f()$ for each of the p parameters:

$$\begin{aligned}XB &= ADESIGN*BETA + BDESIGN*B \\PHI &= f(XB)\end{aligned}$$

Each element of the vector must be one of the following integer codes specifying the transformation for the corresponding value of PHI:

- 0: $PHI = XB$ (default for all parameters)
- 1: $\log(PHI) = XB$
- 2: $\text{probit}(PHI) = XB$
- 3: $\text{logit}(PHI) = XB$

Replicates

Number REPS of estimations to perform starting from the starting values in the vector BETA0. If BETA0 is a matrix, REPS must match the number of columns in BETA0. Default is the number of columns in BETA0.

Vectorization

Determines the possible sizes of the PHI, XFUN, and VFUN input arguments to MODELFUN. Possible values are:

- 'SinglePhi' — MODELFUN is a function (such as an ODE solver) that can only compute YFIT for a single set of model parameters at a time, i.e., PHI must be a single row vector in each call. nlmefitsa calls MODELFUN in a loop if necessary using a single PHI vector and with XFUN containing rows for a single observation or group at a time. VFUN may be a single row that applies to all rows of XFUN, or a matrix with rows corresponding to rows in XFUN.
- 'SingleGroup' — MODELFUN can only accept inputs corresponding to a single group in the data, i.e., XFUN must contain rows of X from a single group in each call. Depending on the model, PHI is a single row that applies to the entire group, or a matrix with one row for each observation. VFUN is a single row.
- 'Full' — MODELFUN can accept inputs for multiple parameter vectors and multiple groups in the data. Either PHI or VFUN may be a single row that applies to all rows of XFUN, or a matrix with rows corresponding to rows in XFUN. Using this option can improve performance by reducing the number of calls to MODELFUN, but may require MODELFUN to perform singleton expansion on PHI or V.

The default for 'Vectorization' is 'SinglePhi'. In all cases, if V is empty, nlmefitsa calls MODELFUN with only two inputs.

Output Arguments

BETA

Estimates of the fixed effects

PSI

An r -by- r estimated covariance matrix for the random effects. By default, r is equal to the number of model parameters p .

STATS

A structure with the following fields:

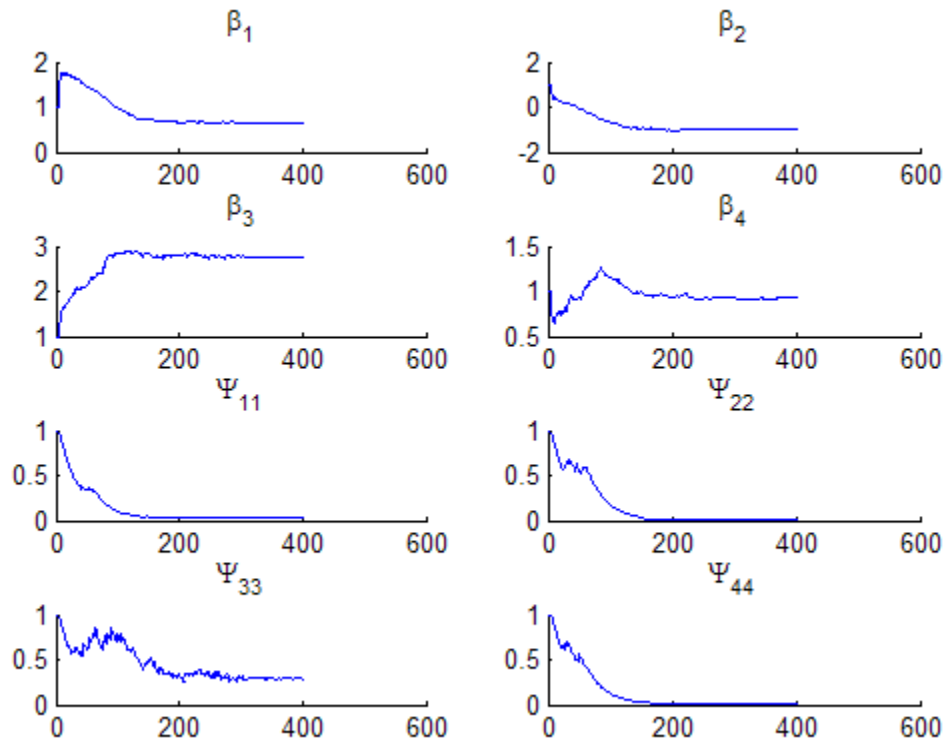
- logl — The maximized loglikelihood for the fitted model; empty if the LogLikMethod parameter has its default value of 'none'

- `rmse` — The square root of the estimated error variance (computed on the log scale for the exponential error model)
- `errorparam` — The estimated parameters of the error variance model
- `aic` — The Akaike information criterion (empty if `logl` is empty), calculated as $\text{aic} = -2 * \text{logl} + 2 * \text{numParam}$, where
 - `logl` is the maximized loglikelihood.
 - `numParam` is the number of fitting parameters, including the degree of freedom for covariance matrix of the random effects, the number of fixed effects and the number of parameters of the error model.
- `bic` — The Bayesian information criterion (empty if `logl` is empty), calculated as $\text{bic} = -2 * \text{logl} + \log(M) * \text{numParam}$
 - `M` is the number of groups.
 - `logl` and `numParam` are defined as in `aic`.
Note that some literature suggests that the computation of `bic` should be , $\text{bic} = -2 * \text{logl} + \log(N) * \text{numParam}$, where `N` is the number of observations. To adjust the value of the output you can redefine `bic` as follows: $\text{bic} = \text{bic} - \text{numel}(\text{unique}(\text{group})) + \text{numel}(Y)$
- `sebeta` — The standard errors for BETA (empty if the `ComputeStdErrors` parameter has its default value of false)
- `covb` — The estimated covariance of the parameter estimates (empty if `ComputeStdErrors` is false)
- `dfe` — The error degrees of freedom
- `pres` — The population residuals ($y - y_{\text{population}}$), where `y_population` is the population predicted values
- `ires` — The population residuals ($y - y_{\text{population}}$), where `y_population` is the individual predicted values
- `pwres` — The population weighted residuals
- `cwres` — The conditional weighted residuals
- `iwres` — The individual weighted residuals

Examples

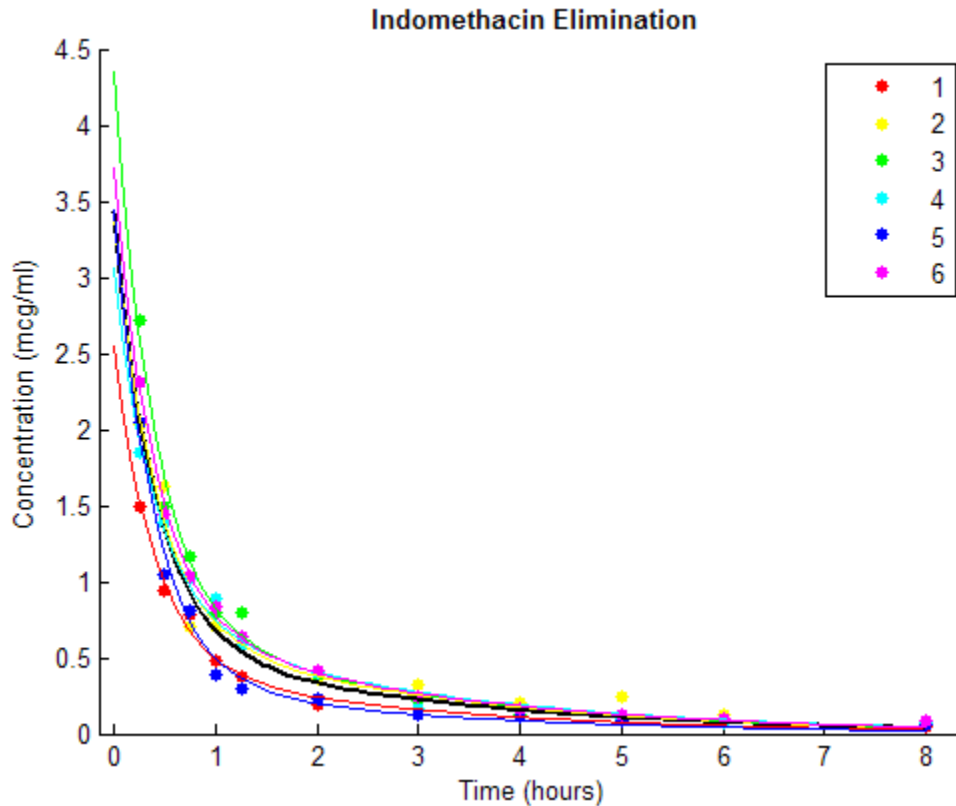
Fit a model to data on concentrations of the drug indomethacin in the bloodstream of six subjects over eight hours:

```
load indomethacin
model = @(phi,t)(phi(:,1).*exp(-phi(:,2).*t)+phi(:,3).*exp(-phi(:,4).*t));
phi0 = [1 1 1 1];
% log transform for 2nd and 4th parameters
xform = [0 1 0 1];
[beta,PSI,stats,br] = nlmefitsa(time,concentration,...
    subject,[],model,phi0,'ParamTransform',xform)
```



```
% Plot the data along with an overall "population" fit
clf
phi = [beta(1), exp(beta(2)), beta(3), exp(beta(4))];
h = gscatter(time,concentration,subject);
xlabel('Time (hours)')
ylabel('Concentration (mcg/ml)')
title('{\bf Indomethacin Elimination}')
xx = linspace(0,8);
line(xx,model(phi,xx),'linewidth',2,'color','k')

% Plot individual curves based on random effect estimates
for j=1:6
    phir = [beta(1)+br(1,j), exp(beta(2)+br(2,j)), ...
            beta(3)+br(3,j), exp(beta(4)+br(4,j))];
    line(xx,model(phir,xx),'color',get(h(j),'color'))
end
```



Algorithms

In order to estimate the parameters of a nonlinear mixed effects model, we would like to choose the parameter values that maximize a likelihood function. These values are called the maximum likelihood estimates. The likelihood function can be written in the form

$$p(y | \beta, \sigma^2, \Sigma) = \int p(y | \beta, b, \sigma^2) p(b | \Sigma) db$$

where

- y is the response data

- β is the vector of population coefficients
- σ^2 is the residual variance
- Σ is the covariance matrix for the random effects
- b is the set of unobserved random effects

Each $p()$ function on the right-hand-side is a normal (Gaussian) likelihood function that may depend on covariates.

Since the integral does not have a closed form, it is difficult to find parameters that maximize it. Delyon, Lavielle, and Moulines [1] proposed to find the maximum likelihood estimates using an Expectation-Maximization (EM) algorithm in which the E step is replaced by a stochastic procedure. They called their algorithm SAEM, for Stochastic Approximation EM. They demonstrated that this algorithm has desirable theoretical properties, including convergence under practical conditions and convergence to a local maximum of the likelihood function. Their proposal involves three steps:

- 1** Simulation: Generate simulated values of the random effects b from the posterior density $p(b | \Sigma)$ given the current parameter estimates.
- 2** Stochastic approximation: Update the expected value of the loglikelihood function by taking its value from the previous step, and moving part way toward the average value of the loglikelihood calculated from the simulated random effects.
- 3** Maximization step: Choose new parameter estimates to maximize the loglikelihood function given the simulated values of the random effects.

References

- [1] Delyon, B., M. Lavielle, and E. Moulines, *Convergence of a stochastic approximation version of the EM algorithm*, Annals of Statistics, 27, 94-128, 1999.
- [2] Mentré, France, and Marc Lavielle, *Stochastic EM algorithms in population PKPD analyses*, 2008.

See Also `nlinfit` | `nlpredci` | `nlmefit`

- How To**
- “Mixed-Effects Models” on page 9-217
 - “Grouping Variables” on page 2-72

gmdistribution.NlogL property

Purpose Negative of log-likelihood

Description The negative of the log-likelihood of the data.

Note This property applies only to gmdistribution objects constructed with `fit`.

ProbDistParametric.NLogL property

Purpose	Read-only value specifying negative log likelihood for input data to ProbDistParametric object
Description	NLogL is a read-only property of the ProbDistParametric class. NLogL is a value specifying the negative log likelihood for input data used to fit a distribution represented by a ProbDistParametric object.
Values	The value is a numeric scalar for a distribution fit to input data, that is, a distribution created using the <code>fitdist</code> function. This property is empty for distributions created without fitting to data, that is, by using the <code>ProbDistUnivParam.ProbDistUnivParam</code> constructor. Use this information to view and compare the negative log likelihood for input data supplied to create distributions.

ProbDistUnivKernel.NLogL property

Purpose	Read-only value specifying negative log likelihood for input data to ProbDistUnivKernel object
Description	NLogL is a read-only property of the ProbDistUnivKernel class. NLogL is a value specifying the negative log likelihood for input data used to fit a distribution represented by a ProbDistUnivKernel object.
Values	The value is a numeric scalar for a distribution fit to input data, that is, a distribution created using the <code>fitdist</code> function. Use this information to view and compare the negative log likelihood for input data used to create distributions.

Purpose

Nonlinear regression parameter confidence intervals

Syntax

```
ci = nlparci(beta,resid,'covar',sigma)
ci = nlparci(beta,resid,'jacobian',J)
ci = nlparci(...,'alpha',alpha)
```

Description

`ci = nlparci(beta,resid,'covar',sigma)` returns the 95% confidence intervals `ci` for the nonlinear least squares parameter estimates `beta`. Before calling `nlparci`, use `nlinfit` to fit a nonlinear regression model and get the coefficient estimates `beta`, residuals `resid`, and estimated coefficient covariance matrix `sigma`.

`ci = nlparci(beta,resid,'jacobian',J)` is an alternative syntax that also computes 95% confidence intervals. `J` is the Jacobian computed by `nlinfit`. If the 'robust' option is used with `nlinfit`, use the 'covar' input rather than the 'jacobian' input so that the required `sigma` parameter takes the robust fitting into account.

`ci = nlparci(...,'alpha',alpha)` returns 100(1-alpha)% confidence intervals.

`nlparci` treats NaNs in `resid` or `J` as missing values, and ignores the corresponding observations.

The confidence interval calculation is valid for systems where the length of `resid` exceeds the length of `beta` and `J` has full column rank. When `J` is ill-conditioned, confidence intervals may be inaccurate.

Examples**Fit to exponential decay**

Suppose you have data, and want to fit a model of the form

$$y_i = a_1 + a_2 \exp(-a_3 x_i) + \varepsilon_i.$$

Here the a_i are the parameters you want to estimate, x_i are the data points, the y_i are the responses, and the ε_i are noise terms.

1 Write a function handle that represents the model:

```
mdl = @(a,x)(a(1) + a(2)*exp(-a(3)*x));
```

- 2** Generate synthetic data with parameters $a = [1;3;2]$, with the x data points distributed exponentially with parameter 2, and normally distributed noise with standard deviation 0.1:

```
rng(9845,'twister') % for reproducibility
a = [1;3;2];
x = exprnd(2,100,1);
epsn = normrnd(0,0.1,100,1);
y = mdl(a,x) + epsn;
```

- 3** Fit the model to data starting from the arbitrary guess $a_0 = [2;2;2]$:

```
a0 = [2;2;2];
[ahat,r,J,cov,mse] = nlinfit(x,y,mdl,a0);
ahat
```

```
ahat =
    1.0153
    3.0229
    2.1070
```

- 4** Check whether $[1;3;2]$ is in a 95% confidence interval using the Jacobian argument in `nlparci`:

```
ci = nlparci(ahat,r,'Jacobian',J)
```

```
ci =
    0.9869    1.0438
    2.9401    3.1058
    1.9963    2.2177
```

- 5** You can obtain the same result using the covariance argument:

```
ci = nlparci(ahat,r,'covar',cov)
```

```
ci =
    0.9869    1.0438
```

2.9401 3.1058
1.9963 2.2177

See Also `nlinfit` | `nlpredci`

nlpredci

Purpose

Nonlinear regression prediction confidence intervals

Syntax

```
[Ypred,delta] = nlpredci(modelfun,X,beta,R,'Covar',CovB)
[Ypred,delta] =
nlpredci(modelfun,X,beta,R,'Covar',CovB,Name,
          Value)
```

```
[Ypred,delta] = nlpredci(modelfun,X,beta,R,'Jacobian',J)
[Ypred,delta] =
nlpredci(modelfun,X,beta,R,'Jacobian',J,Name,
          Value)
```

Description

[Ypred,delta] = nlpredci(modelfun,X,beta,R,'Covar',CovB) returns predictions, Ypred, and 95% confidence interval half-widths, delta, for the nonlinear regression model modelfun at input values X. Before calling nlpredci, use nlinfit to fit modelfun and get the estimated coefficients, beta, residuals, R, and variance-covariance matrix, CovB.

[Ypred,delta] = nlpredci(modelfun,X,beta,R,'Covar',CovB,Name,Value) uses additional options specified by one or more name-value pair arguments.

[Ypred,delta] = nlpredci(modelfun,X,beta,R,'Jacobian',J) returns predictions, Ypred, and 95% confidence interval half-widths, delta, for the nonlinear regression model modelfun at input values X. Before calling nlpredci, use nlinfit to fit modelfun and get the estimated coefficients, beta, residuals, R, and Jacobian, J.

If you use a robust option with nlinfit, then you should use the Covar syntax rather than the Jacobian syntax. The variance-covariance matrix, CovB, is required to properly take the robust fitting into account.

[Ypred,delta] = nlpredci(modelfun,X,beta,R,'Jacobian',J,Name,Value) uses additional options specified by one or more name-value pair arguments.

Input Arguments

modelfun - Nonlinear regression model function

function handle

Nonlinear regression model function, specified as a function handle. `modelfun` must accept two input arguments, a coefficient vector and an array X —in that order—and return a vector of fitted response values.

For example, to specify the `hougen` nonlinear regression function, use the function handle `@hougen`.

Data Types

function_handle

X - Input values for predictions

matrix

Input values for predictions, specified as a matrix. `nlpredci` makes a prediction for the covariates in each row of X . There should be a column in X for each coefficient in the model.

Data Types

single | double

beta - Estimated regression coefficients

vector

Estimated regression coefficients, specified as the vector of fitted coefficients returned by `nlinfit`.

Data Types

single | double

R - Residuals

vector

Residuals for the fitted `modelfun`, specified as the vector of residuals returned by `nlinfit`.

CovB - Estimated variance-covariance matrix

matrix

Estimated variance-covariance matrix for the fitted coefficients, `beta`, specified as the variance-covariance matrix returned by `nlinfit`.

J - Estimated Jacobian

matrix

Estimated Jacobian of the nonlinear regression model, `modelfun`, specified as the Jacobian matrix returned by `nlinfit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'Alpha',0.1,'PredOpt','observation'` specifies 90% prediction intervals for new observations.

Alpha - Significance level

0.05 (default) | scalar value in the range (0,1)

Significance level for the confidence interval, specified as the comma-separated pair consisting of `'Alpha'` and a scalar value in the range (0,1). If `Alpha` has value α , then `nlpredci` returns intervals with $100 \times (1 - \alpha)\%$ confidence level.

The default confidence level is 95% ($\alpha = 0.05$).

Example: `'Alpha',0.1`

Data Types

single | double

MSE - Mean squared error

MSE returned by `nlinfit`

Mean squared error (MSE) for the fitted nonlinear regression model, specified as the comma-separated pair consisting of `'MSE'` and the MSE value returned by `nlinfit`.

If you use a robust option with `nlinfit`, then you must specify the MSE when predicting new observations to properly take the robust fitting into account. If you do not specify the MSE, then `nlpredci` computes the MSE from the residuals, `R`, and does not take the robust fitting into account.

For example, if `mse` is the MSE value returned by `nlinfit`, then you can specify `'MSE',mse`.

Data Types

single | double

PredOpt - Prediction interval to compute

`'curve'` (default) | `'observation'`

Prediction interval to compute, specified as the comma-separated pair consisting of `'PredOpt'` and either `'curve'` or `'observation'`.

- If you specify the value `'curve'`, then `nlpredci` returns confidence intervals for the estimated curve (function value) at the observations `X`.
- If you specify the value `'observation'`, then `nlpredci` returns prediction intervals for new observations at `X`.

If you specify `'observation'` after using a robust option with `nlinfit`, then you must also specify a value for MSE to provide the robust estimate of the mean squared error.

Example: `'PredOpt','observation'`

Data Types

char

SimOpt - Indicator for specifying simultaneous bounds

`'off'` (default) | `'on'`

Indicator for specifying simultaneous bounds, specified as the comma-separated pair consisting of `'SimOpt'` and either `'off'` or `'on'`. Use the value `'off'` to compute nonsimultaneous bounds, and `'on'` for simultaneous bounds.

Weights - Observation weights

vector | function handle

Observation weights, specified as the comma-separated pair consisting of 'Weights' and a vector of positive scalar values or a function handle. The default is no weights.

- If you specify a vector of weights, then it must have the same number of elements as the number of observations (rows) in X.
- If you specify a function handle for the weights, then it must accept a vector of predicted response values as input, and return a vector of real positive weights as output.

Given weights, W, `nlpredci` estimates the error variance at observation *i* by $mse * (1/W(i))$, where *mse* is the mean squared error value specified using MSE.

Example: 'Weights',@WFun

Data Types

double | single | function_handle

Output Arguments

Ypred - Predicted responses

vector

Predicted responses, returned as a vector with the same number of rows as X.

delta - Confidence interval half-widths

vector

Confidence interval half-widths, returned as a vector with the same number of rows as X. By default, `delta` contains the half-widths for nonsimultaneous 95% confidence intervals for `modelfun` at the observations in X. You can compute the lower and upper bounds of the confidence intervals as `Ypred-delta` and `Ypred+delta`, respectively.

If 'PredOpt' has value 'observation', then `delta` contains the half-widths for prediction intervals of new observations at the values in X.

Examples**Confidence Interval for Nonlinear Regression Curve**

Load sample data.

```
S = load('reaction');
X = S.reactants;
y = S.rate;
beta0 = S.beta;
```

Fit the Hougen-Watson model to the rate data using the initial values in beta0.

```
[beta,R,J] = nlinfit(X,y,@hougen,beta0);
```

Obtain the predicted response and 95% confidence interval half-width for the value of the curve at average reactant levels.

```
[ypred,delta] = nlpredci(@hougen,mean(X),beta,R,'Jacobian',J)
```

```
ypred =
```

```
5.4622
```

```
delta =
```

```
0.1921
```

Compute the 95% confidence interval for the value of the curve.

```
[ypred-delta,ypred+delta]
```

```
ans =
```

```
5.2702    5.6543
```

Prediction Interval for New Observation

Load sample data.

```
S = load('reaction');  
X = S.reactants;  
y = S.rate;  
beta0 = S.beta;
```

Fit the Hougen-Watson model to the rate data using the initial values in beta0.

```
[beta,R,J] = nlinfit(X,y,@hougen,beta0);
```

Obtain the predicted response and 95% prediction interval half-width for a new observation with reactant levels [100,100,100].

```
[ypred,delta] = nlpredci(@hougen,[100,100,100],beta,R,'Jacobian',J,...  
                        'PredOpt','observation')
```

```
ypred =
```

```
    1.8346
```

```
delta =
```

```
    0.5101
```

Compute the 95% prediction interval for the new observation.

```
[ypred-delta,ypred+delta]
```

```
ans =
```

```
    1.3245    2.3447
```

Simultaneous Confidence Intervals for Robust Fit Curve

Generate sample data from the nonlinear regression model

$$y = b_1 + b_2 \exp\{-b_3 x\} + \varepsilon,$$

where b_1 , b_2 , and b_3 are coefficients, and the error term is normally distributed with mean 0 and standard deviation 0.5.

```
modelfun = @(b,x)(b(1)+b(2)*exp(-b(3)*x));
```

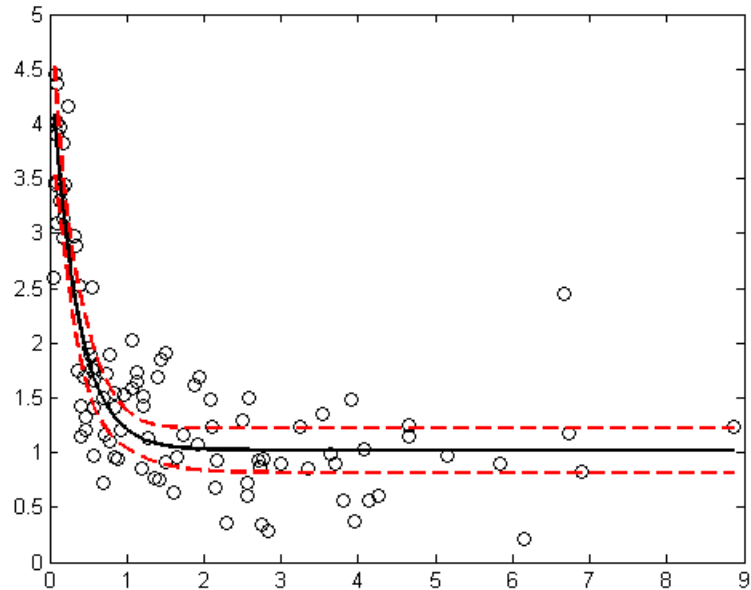
```
rng('default') % for reproducibility  
b = [1;3;2];  
x = exprnd(2,100,1);  
y = modelfun(b,x) + normrnd(0,0.5,100,1);
```

Fit the nonlinear model using robust fitting options.

```
opts = statset('nlinfit');  
opts.RobustWgtFun = 'bisquare';  
beta0 = [2;2;2];  
[beta,R,J,CovB,MSE] = nlinfit(x,y,modelfun,beta0,opts);
```

Plot the fitted regression model and simultaneous 95% confidence bounds.

```
xrange = min(x):.01:max(x);  
[ypred,delta] = nlpredci(modelfun,xrange,beta,R,'Covar',CovB,...  
                        'MSE',MSE,'SimOpt','on');  
lower = ypred - delta;  
upper = ypred + delta;  
  
figure()  
plot(x,y,'ko') % observed data  
hold on  
plot(xrange,ypred,'k','LineWidth',2)  
plot(xrange,[lower;upper],'r--','LineWidth',1.5)
```



Confidence Interval Using Observation Weights

Load sample data.

```
S = load('reaction');  
X = S.reactants;  
y = S.rate;  
beta0 = S.beta;
```

Specify a function handle for observation weights, then fit the Hougen-Watson model to the rate data using the specified observation weights function.

```
a = 1; b = 1;  
weights = @(yhat) 1./((a + b*abs(yhat)).^2);  
[beta,R,J,CovB] = nlinfit(X,y,@hougen,beta0,'Weights',weights);
```

Compute the 95% prediction interval for a new observation with reactant levels [100, 100, 100] using the observation weight function.

```
[ypred,delta] = nlpredci(@hougen,[100,100,100],beta,R,'Jacobian',J,...
                        'PredOpt','observation','Weights',weights);
[ypred-delta,ypred+delta]
```

```
ans =
```

```
1.5264    2.1033
```

Algorithms

- nlpredci treats NaN values in the residuals, R, or the Jacobian, J, as missing values, and ignores the corresponding observations.
- If the Jacobian, J, does not have full column rank, then some of the model parameters might be nonidentifiable. In this case, nlpredci tries to construct confidence intervals for estimable predictions, and returns NaN for those that are not.

Definitions

Confidence Intervals for Estimable Predictions

When the estimated model Jacobian is not of full rank, then it might not be possible to construct sensible confidence intervals at all prediction points. In this case, nlpredci still tries to construct confidence intervals for any *estimable* prediction points.

For example, suppose you fit the linear function

$f(\mathbf{x}_i, \beta) = \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3}$ at the points in the design matrix

$$\mathbf{X} = \begin{pmatrix} 1 & 1 & 0 \\ 1 & 1 & 0 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \\ 1 & 0 & 1 \\ 1 & 0 & 1 \end{pmatrix}.$$

The estimated Jacobian at the values in \mathbf{X} is the design matrix itself, $\mathbf{J} = \mathbf{X}$. Thus, the Jacobian is not of full rank:

```
rng('default') % For reproducibility
y = randn(6,1);

linfun = @(b,x) x*b;
beta0 = [1;1;1];
X = [repmat([1 1 0],3,1); repmat([1 0 1],3,1)];

[beta,R,J] = nlinfit(X,y,linfun,beta0);
```

```
Warning: The Jacobian at the solution is ill-conditioned, and
some model parameters may not be estimated well (they are not
identifiable). Use caution in making predictions.
> In nlinfit at 283
```

In this example, `nlpredci` can only compute prediction intervals at points that satisfy the linear relationship

$$x_{i1} = x_{i2} + x_{i3}.$$

If you try to compute confidence intervals for predictions at nonidentifiable points, `nlpredci` returns NaN for the corresponding interval half-widths:

```
xpred = [1 1 1;0 1 -1;2 1 1];
[ypred,delta] = nlpredci(linfun,xpred,beta,R,'Jacobian',J)

ypred =

    -0.0035
     0.0798
    -0.0047

delta =
```

```
      NaN
      3.8102
      3.8102
```

Here, the first element of `delta` is NaN because the first row in `xpred` does not satisfy the required linear dependence, and is therefore not an estimable contrast.

References

- [1] Lane, T. P. and W. H. DuMouchel. "Simultaneous Confidence Intervals in Multiple Regression." *The American Statistician*. Vol. 48, No. 4, 1994, pp. 315–321.
- [2] Seber, G. A. F., and C. J. Wild. *Nonlinear Regression*. Hoboken, NJ: Wiley-Interscience, 2003.

See Also

`nlinfit` | `nlparciNonLinearModel` |

nnmf

Purpose Nonnegative matrix factorization

Syntax
 $[W,H] = \text{nnmf}(A,k)$
 $[W,H] = \text{nnmf}(A,k,param1,val1,param2,val2,...)$
 $[W,H,D] = \text{nnmf}(...)$

Description $[W,H] = \text{nnmf}(A,k)$ factors the nonnegative n -by- m matrix A into nonnegative factors W (n -by- k) and H (k -by- m). The factorization is not exact; $W*H$ is a lower-rank approximation to A . The factors W and H are chosen to minimize the root-mean-squared residual D between A and $W*H$:

$$D = \text{sqrt}(\text{norm}(A-W*H, 'fro') / (N*M))$$

The factorization uses an iterative method starting with random initial values for W and H . Because the root-mean-squared residual D may have local minima, repeated factorizations may yield different W and H . Sometimes the algorithm converges to a solution of lower rank than k , which may indicate that the result is not optimal.

W and H are normalized so that the rows of H have unit length. The columns of W are ordered by decreasing length.

$[W,H] = \text{nnmf}(A,k,param1,val1,param2,val2,...)$ specifies optional parameter name/value pairs from the following table.

Parameter	Value
'algorithm'	<p>Either 'als' (the default) to use an alternating least-squares algorithm, or 'mult' to use a multiplicative update algorithm.</p> <p>In general, the 'als' algorithm converges faster and more consistently. The 'mult' algorithm is more sensitive to initial values, which makes it a</p>

Parameter	Value
	good choice when using 'replicates' to find W and H from multiple random starting values.
'w0'	An n -by- k matrix to be used as the initial value for W.
'h0'	A k -by- m matrix to be used as the initial value for H.
'options'	<p>An options structure as created by the <code>statset</code> function. <code>nnmf</code> uses the following fields of the options structure:</p> <ul style="list-style-type: none"> • Display — Level of display. Choices: <ul style="list-style-type: none"> ▪ 'off' (default) — No display ▪ 'final' — Display final result ▪ 'iter' — Iterative display of intermediate results • MaxIter — Maximum number of iterations. Default is 100. Unlike in optimization settings, reaching <code>MaxIter</code> iterations is treated as convergence. • TolFun — Termination tolerance on change in size of the residual. Default is $1e-4$. • TolX — Termination tolerance on relative change in the elements of W and H. Default is $1e-4$. • UseParallel — Set to 'always' to compute in parallel. Default is 'never'. • UseSubstreams — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set

Parameter	Value
	<p>Streams to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'.</p> <ul style="list-style-type: none"> Streams — A RandStream object or cell array of such objects. If you do not specify Streams, nnmf uses the default stream or streams. If you choose to specify Streams, use a single object except in the case <ul style="list-style-type: none"> You have an open MATLAB pool UseParallel is 'always' UseSubstreams is 'never' <p>In that case, use a cell array the same size as the MATLAB pool.</p>
'replicates'	<p>The number of times to repeat the factorization, using new random starting values for W and H, except at the first replication if 'w0' and 'h0' are given. This is most beneficial with the 'mult' algorithm. The default is 1.</p>

[W,H,D] = nnmf(...) also returns D, the root mean square residual.

Examples

Example 1

Compute a nonnegative rank-two approximation of the measurements of the four variables in Fisher's iris data:

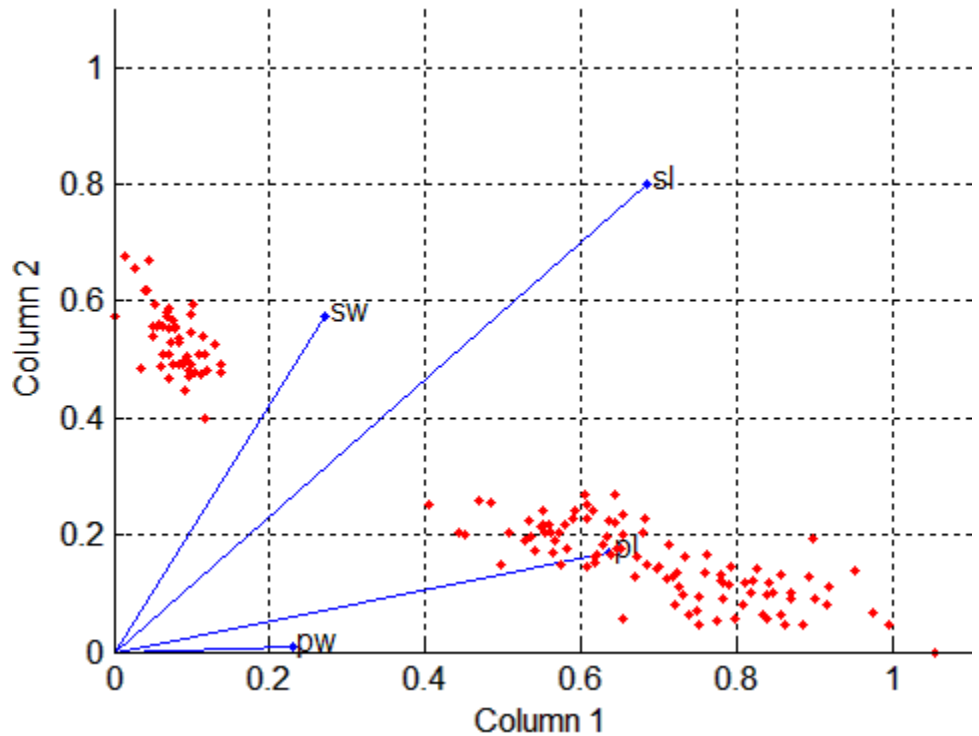
```
load fisheriris
[W,H] = nnmf(meas,2);
H
H =
    0.6852    0.2719    0.6357    0.2288
    0.8011    0.5740    0.1694    0.0087
```

The first and third variables in meas (sepal length and petal length, with coefficients 0.6852 and 0.6357, respectively) provide relatively

strong weights to the first column of W . The first and second variables in `meas` (sepal length and sepal width, with coefficients 0.8011 and 0.5740) provide relatively strong weights to the second column of W .

Create a biplot of the data and the variables in `meas` in the column space of W :

```
biplot(H', 'scores', W, 'varlabels', {'sl', 'sw', 'pl', 'pw'});  
axis([0 1.1 0 1.1])  
xlabel('Column 1')  
ylabel('Column 2')
```



Example 2

Starting from a random array X with rank 20, try a few iterations at several replicates using the multiplicative algorithm:

```
X = rand(100,20)*rand(20,50);
opt = statset('MaxIter',5,'Display','final');
[WO,H0] = nnmf(X,5,'replicates',10,...
               'options',opt,...
               'algorithm','mult');
```

rep	iteration	rms resid	delta x
1	5	0.560887	0.0245182
2	5	0.66418	0.0364471
3	5	0.609125	0.0358355
4	5	0.608894	0.0415491
5	5	0.619291	0.0455135
6	5	0.621549	0.0299965
7	5	0.640549	0.0438758
8	5	0.673015	0.0366856
9	5	0.606835	0.0318931
10	5	0.633526	0.0319591

Final root mean square residual = 0.560887

Continue with more iterations from the best of these results using alternating least squares:

```
opt = statset('Maxiter',1000,'Display','final');
[W,H] = nnmf(X,5,'w0',WO,'h0',H0,...
              'options',opt,...
              'algorithm','als');
```

rep	iteration	rms resid	delta x
1	80	0.256914	9.78625e-005

Final root mean square residual = 0.256914

References

[1] Berry, M. W., et al. "Algorithms and Applications for Approximate Nonnegative Matrix Factorization." *Computational Statistics and Data Analysis*. Vol. 52, No. 1, 2007, pp. 155–173.

See Also

pca | factoran | statset

classregtree.nodeclass

Purpose Class values of nodes of classification tree

Syntax NAME=nodeclass(T)
NAME=nodeclass(T,J)
[NAME,ID]=nodeclass(...)

Description NAME=nodeclass(T) returns an n -element cell array with the names of the most probable classes in each node of the tree T, where n is the number of nodes in the tree. Every element of this array is a string equal to one of the class names returned by `classname(T)`. For regression trees, `nodeclass` returns an empty cell array.

NAME=nodeclass(T,J) takes an array J of node numbers and returns the class names for the specified nodes.

[NAME,ID]=nodeclass(...) also returns a numeric array with the class index for each node. The class index is determined by the order of classes `classname` returns.

See Also classregtree | classname | numnodes

Purpose Return vector of node errors

Syntax
`e = nodeerr(t)`
`e = nodeerr(t,nodes)`

Description `e = nodeerr(t)` returns an n -element vector `e` of the errors of the nodes in the tree `t`, where n is the number of nodes. For a regression tree, the error `e(i)` for node `i` is the variance of the observations assigned to node `i`. For a classification tree, `e(i)` is the misclassification probability for node `i`.

`e = nodeerr(t,nodes)` takes a vector `nodes` of node numbers and returns the errors for the specified nodes.

The error `e` is the so-called *resubstitution error* computed by applying the tree to the same data used to create the tree. This error is likely to under estimate the error you would find if you applied the tree to new data. The `test` function provides options to compute the error (or cost) using cross-validation or a test sample.

Examples Create a classification tree for Fisher's iris data:

```
load fisheriris;

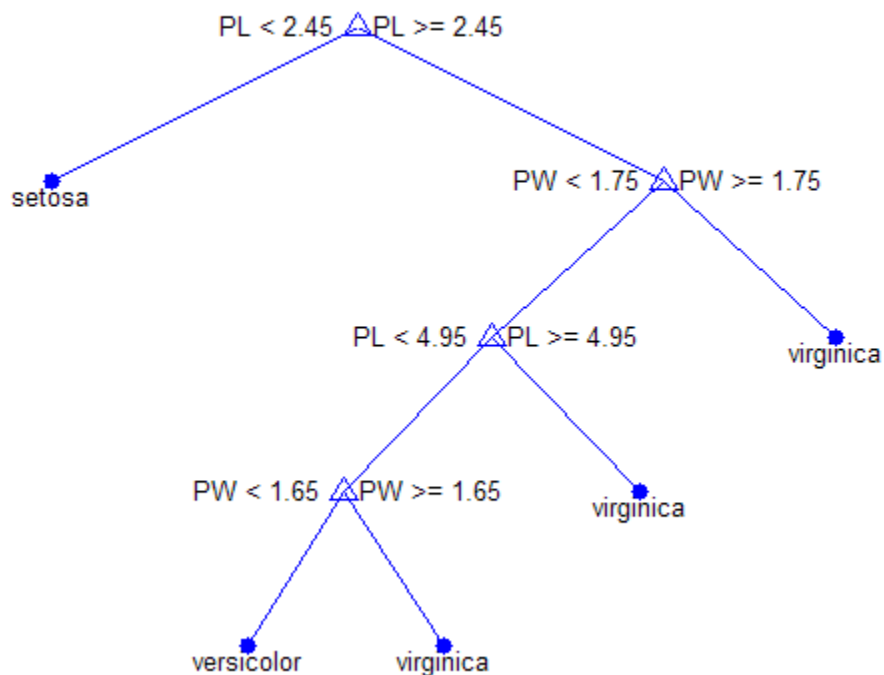
t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})

t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica
```

classregtree.nodeerr

view(t)

Click to display: Magnification: Pruning level:



e = nodeerr(t)

e =
0.6667
0
0.5000
0.0926
0.0217
0.0208


```
0.3333
      0
      0
```

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

`classregtree` | `numnodes` | `test`

classregtree.nodemean

Purpose Mean values of nodes of regression tree

Syntax NM = nodemean(T)
NM = nodemean(T,J)

Description NM = nodemean(T) returns an n -element numeric array with mean values in each node of the tree T, where n is the number of nodes in the tree. Every element of this array is computed by averaging true Y values over all observations in the node. For classification trees, nodemean returns an empty numeric array.

NM = nodemean(T,J) takes an array J of node numbers and returns the mean values for the specified nodes.

See Also classregtree | numnodes

Purpose

Node probabilities

Syntax

```
p = nodeprob(t)
p = nodeprob(t,nodes)
```

Description

`p = nodeprob(t)` returns an n -element vector `p` of the probabilities of the nodes in the tree `t`, where n is the number of nodes. The probability of a node is computed as the proportion of observations from the original data that satisfy the conditions for the node. For a classification tree, this proportion is adjusted for any prior probabilities assigned to each class.

`p = nodeprob(t,nodes)` takes a vector `nodes` of node numbers and returns the probabilities for the specified nodes.

Examples

Create a classification tree for Fisher's iris data:

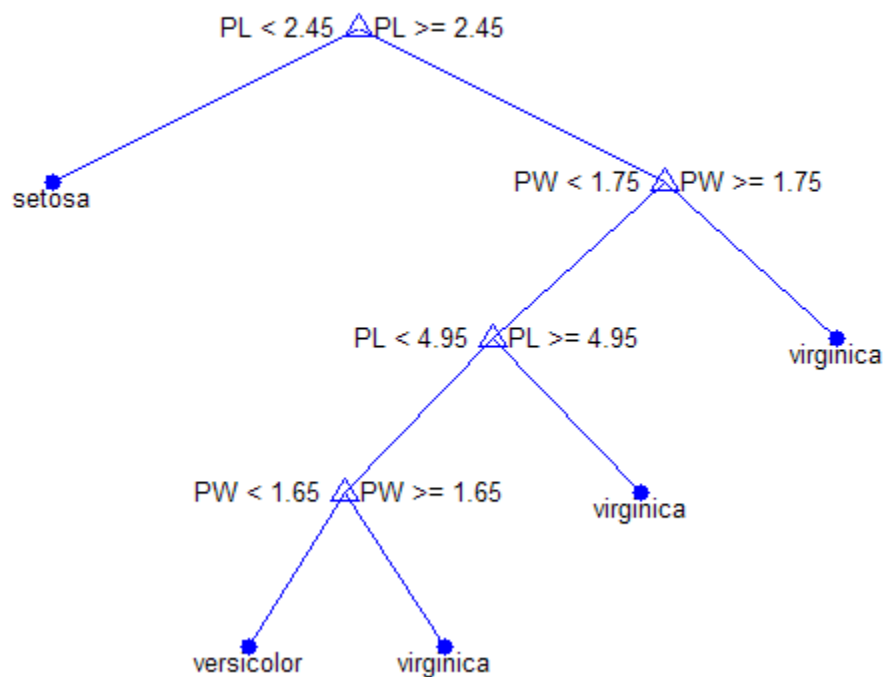
```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

classregtree.nodeprob

Click to display: Magnification: Pruning level:



p = nodeprob(t)

p =

1.0000

0.3333

0.6667

0.3600

0.3067

0.3200

0.0400

0.3133

0.0067

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree | nodesize | numnodes

classregtree.nodesize

Purpose Return node size

Syntax `sizes = nodesize(t)`
`sizes = nodesize(t,nodes)`

Description `sizes = nodesize(t)` returns an n -element vector `sizes` of the sizes of the nodes in the tree `t`, where n is the number of nodes. The size of a node is defined as the number of observations from the data used to create the tree that satisfy the conditions for the node.

`sizes = nodesize(t,nodes)` takes a vector `nodes` of node numbers and returns the sizes for the specified nodes.

Examples Create a classification tree for Fisher's iris data:

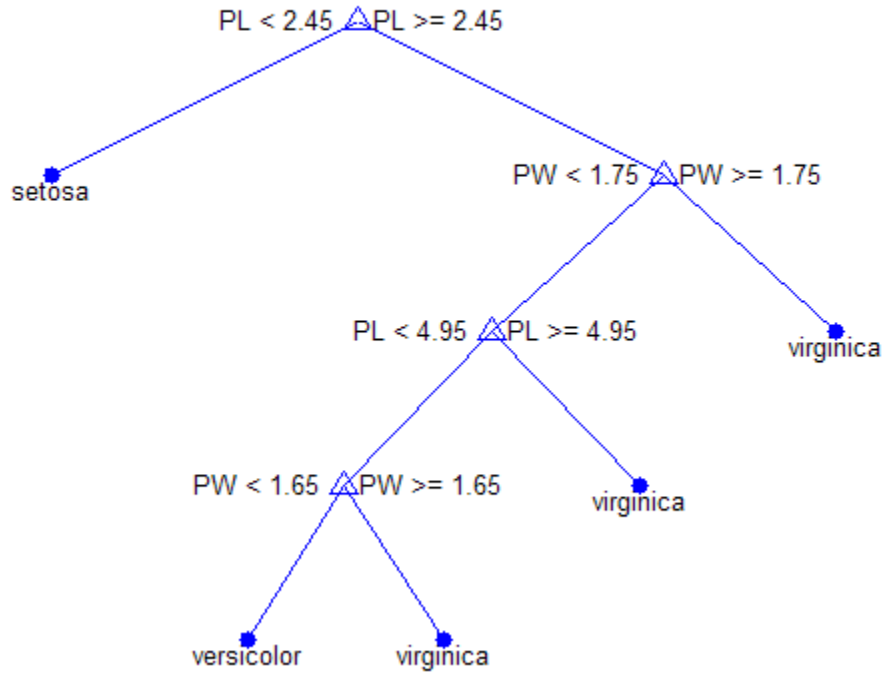
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load fisheriris;

t = classregtree(meas,species,...
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5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

classregtree.nodesize

Click to display: Magnification: Pruning level:



```
sizes = nodesize(t)
sizes =
    150
     50
    100
     54
     46
     48
     6
     47
```

classregtree.nodesize

1

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

`classregtree` | `numnodes`

Purpose Notify listeners of event

Syntax `notify(h, 'eventname')`
`notify(h, 'eventname', data)`

Description `notify(h, 'eventname')` notifies listeners added to the event named `eventname` on handle object array `h` that the event is taking place. `h` is the array of handles to objects triggering the event, and `eventname` must be a string.

`notify(h, 'eventname', data)` provides a way of encapsulating information about an event which can then be accessed by each registered listener. `data` must belong to the `event.eventdata` class.

See Also `addlistener` | `event.EventData` | `events` | `grandstream`

nominal

Superclasses categorical

Purpose Arrays for nominal categorical data

Description Nominal arrays are used to store discrete values that are not numeric and that do not have an ordering. A nominal array provides efficient storage and convenient manipulation of such data, while also maintaining meaningful labels for the values. Nominal arrays are often used as grouping variables.

You can subscript, concatenate, reshape, etc. nominal arrays much like ordinary numeric arrays. You can test equality between elements of two nominal arrays, or between a nominal array and a single string representing a nominal value.

Construction Use the `nominal` constructor to create a nominal array from a numeric, logical, or character array, or from a cell array of strings.

`nominal` Construct nominal categorical array

Methods Each nominal array carries along a list of possible values that it can store, known as its levels. The list is created when you create a nominal array, and you can access it using the `getlevels` method, or modify it using the `addlevels`, `mergelevels`, or `droplevels` methods. Assignment to the array will also add new levels automatically if the values assigned are not already levels of the array.

You can change the order of the list of levels for a nominal array using the `reorderlevels` method, however, that order has no significance for the values in the array. The order is used only for display purposes, or when you convert the nominal array to numeric values using methods such as `double` or `subsindex`, or compare two arrays using `isequal`. If you need to work with values that have a mathematical ordering, you should use an `ordinal` array instead.

Inherited Methods

Methods in the following table are inherited from `categorical`.

<code>addlevels</code>	Add levels to categorical array
<code>cat</code>	Concatenate categorical arrays
<code>cellstr</code>	Convert categorical array to cell array of strings
<code>char</code>	Convert categorical array to character array
<code>circshift</code>	Shift categorical array circularly
<code>ctranspose</code>	Transpose categorical matrix
<code>disp</code>	Display categorical array
<code>display</code>	Display categorical array
<code>double</code>	Convert categorical array to double array
<code>droplevels</code>	Drop levels
<code>end</code>	Last index in indexing expression for categorical array
<code>flipdim</code>	Flip categorical array along specified dimension
<code>fliplr</code>	Flip categorical matrix in left/right direction
<code>flipud</code>	Flip categorical matrix in up/down direction
<code>getlabels</code>	Access categorical array labels
<code>getlevels</code>	Get categorical array levels
<code>hist</code>	Plot histogram of categorical data

nominal

horzcat	Horizontal concatenation for categorical arrays
int16	Convert categorical array to signed 16-bit integer array
int32	Convert categorical array to signed 32-bit integer array
int64	Convert categorical array to signed 64-bit integer array
int8	Convert categorical array to signed 8-bit integer array
intersect	Set intersection for categorical arrays
ipermute	Inverse permute dimensions of categorical array
isempty	True for empty categorical array
isequal	True if categorical arrays are equal
islevel	Test for levels
ismember	True for elements of categorical array in set
isscalar	True if categorical array is scalar
isundefined	Test for undefined elements
isvector	True if categorical array is vector
length	Length of categorical array
levelcounts	Element counts by level
ndims	Number of dimensions of categorical array
numel	Number of elements in categorical array

permute	Permute dimensions of categorical array
reorderlevels	Reorder levels
repmat	Replicate and tile categorical array
reshape	Resize categorical array
rot90	Rotate categorical matrix 90 degrees
setdiff	Set difference for categorical arrays
setlabels	Label levels
setxor	Set exclusive-or for categorical arrays
shiftdim	Shift dimensions of categorical array
single	Convert categorical array to single array
size	Size of categorical array
squeeze	Squeeze singleton dimensions from categorical array
subsasgn	Subscripted assignment for categorical array
subsindex	Subscript index for categorical array
subsref	Subscripted reference for categorical array
summary	Summary statistics for categorical array
times	Product of categorical arrays

nominal

<code>transpose</code>	Transpose categorical matrix
<code>uint16</code>	Convert categorical array to unsigned 16-bit integers
<code>uint32</code>	Convert categorical array to unsigned 32-bit integers
<code>uint64</code>	Convert categorical array to unsigned 64-bit integers
<code>uint8</code>	Convert categorical array to unsigned 8-bit integers
<code>union</code>	Set union for categorical arrays
<code>unique</code>	Unique values in categorical array
<code>vertcat</code>	Vertical concatenation for categorical arrays

Properties

Inherited Properties

Properties in the following table are inherited from `categorical`.

<code>labels</code>	Text labels for levels
<code>undeflabel</code>	Text label for undefined levels

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

Examples

Create a nominal array from string data in a cell array:

```
colors = nominal({'r' 'b' 'g'; 'g' 'r' 'b'; 'b' 'r' 'g'}, ...
    {'blue' 'green' 'red'})

% Find elements meeting a criterion
colors == 'red'
```

```
ismember(colors,{'red' 'blue'})

% Compare two nominal arrays
colors2 = fliplr(colors)
colors == colors2
```

See Also

[histc](#) | [ordinal](#)

nominal

Purpose Construct nominal categorical array

Syntax

```
B = nominal(A)
B = nominal(A,labels)
B = nominal(A,labels,levels)
B = nominal(A,labels,[],edges)
```

Description

`B = nominal(A)` creates a nominal array `B` from the array `A`. `A` can be numeric, logical, character, categorical, or a cell array of strings. `nominal` creates the levels of `B` from the sorted unique values in `A`, and creates default labels for them.

`B = nominal(A,labels)` labels the levels in `B` using the character array or cell array of strings `labels`. `nominal` assigns labels to levels in `B` in order according to the sorted unique values in `A`.

`B = nominal(A,labels,levels)` creates a nominal array with possible levels defined by `levels`. `levels` is a vector whose values can be compared to those in `A` using the equality operator. `nominal` assigns labels to each level from the corresponding elements of `labels`. If `A` contains any values not present in `levels`, the levels of the corresponding elements of `B` are undefined.

`B = nominal(A,labels,[],edges)` creates a nominal array by binning the numeric array `A` with bin edges given by the numeric vector `edges`. The uppermost bin includes values equal to the right-most edge. `nominal` assigns labels to each level in `B` from the corresponding elements of `labels`. `edges` must have one more element than `labels`.

By default, an element of `B` is undefined if the corresponding element of `A` is `NaN` (when `A` is numeric), an empty string (when `A` is character), or undefined (when `A` is categorical). `nominal` treats such elements as “undefined” or “missing” and does not include entries for them among the possible levels for `B`. To create an explicit level for such elements instead of treating them as undefined, you must use the `levels` input, and include `NaN`, the empty string, or an undefined element.

You may include duplicate labels in `labels` in order to merge multiple values in `A` into a single level in `B`.

Examples

Create a nominal array from Fisher's iris data:

```
load fisheriris
species = nominal(species);
summary(species)
      setosa      versicolor      virginica
      50          50          50
```

Create a nominal array from characters, and provide explicit labels:

```
colors1 = nominal({'r' 'b' 'g'; 'g' 'r' 'b'; 'b' 'r' 'g'},...
                 {'blue' 'green' 'red'})
```

Create a nominal array from characters, and provide both explicit labels and an explicit order for display:

```
colors2 = nominal({'r' 'b' 'g'; 'g' 'r' 'b'; 'b' 'r' 'g'}, ...
                 {'red' 'green' 'blue'},{'r' 'g' 'b'})
```

Create a nominal array from integer data, merging odd and even values into only two nominal levels. Provide explicit labels:

```
toss = nominal(randi([1 4],5,2),{'odd' 'even' 'odd' 'even'},1:4)
```

- 1 Load patient data from the CSV file `hospital.dat` and store the information in a dataset array with observation names given by the first column in the data (patient identification):

```
patients = dataset('file','hospital.dat',...
                  'delimiter',';',...
                  'ReadObsNames',true);
```

nominal

- 2 Make the {0,1}-valued variable `smoke` nominal, and change the labels to 'No' and 'Yes':

```
patients.smoke = nominal(patients.smoke, {'No', 'Yes'});
```

- 3 Add new levels to `smoke` as placeholders for more detailed histories of smokers:

```
patients.smoke = addlevels(patients.smoke, ...
                           {'0-5 Years', '5-10 Years', 'LongTerm'});
```

- 4 Assuming the nonsmokers have never smoked, relabel the 'No' level:

```
patients.smoke = setlabels(patients.smoke, 'Never', 'No');
```

- 5 Drop the undifferentiated 'Yes' level from `smoke`:

```
patients.smoke = droplevels(patients.smoke, 'Yes');
```

Warning: OLDLEVELS contains categorical levels that were present in A, caused some array elements to have undefined levels.

Note that smokers now have an undefined level.

- 6 Set each smoker to one of the new levels, by observation name:

```
patients.smoke('YPL-320') = '5-10 Years';
```

See Also

`histc` | `ordinal`

Purpose	Nonlinear regression model class
Description	An object comprising training data, model description, diagnostic information, and fitted coefficients for a nonlinear regression. Predict model responses with the <code>predict</code> or <code>feval</code> methods.
Construction	<code>nlm = NonLinearModel.fit(ds,modelfun,beta0)</code> or <code>nlm = NonLinearModel.fit(X,y,modelfun,beta0)</code> create a nonlinear model of a dataset array <code>ds</code> , or of the responses <code>y</code> to a data matrix <code>X</code> . For details, see <code>NonLinearModel.fit</code> .

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors can be numeric, or can be any grouping variable type, such as logical or categorical (see “Grouping Variables” on page 2-72). The response must be numeric or logical.

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

X

Matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as `X`. Each entry in `y` is the response to the data in the corresponding row of `X`.

modelfun

Functional form of the model. Either a:

- Function handle `@modelfun` or `@(b,x)modelfun`, where

NonLinearModel

- **b** is a coefficient vector with the same number of elements as **beta0**.
- **x** is a matrix with the same number of columns as **X** or the data columns of **ds**.

modelfun(**b**,**x**) returns a column vector that contains the same number of rows as **x**. Each row of the vector is the result of evaluating *modelfun* on the corresponding row of **x**. In other words, *modelfun* is a vectorized function, one that operates on all data rows and returns all evaluations in one function call.

- String of the form

$$'y \sim f(b_1, b_2, \dots, b_k, x_1, x_2, \dots, x_k)'$$

f represents a scalar function of the scalar coefficient variables b_1, \dots, b_k and the scalar data variables x_1, \dots, x_k .

beta0

Numeric vector of coefficients for the *modelfun* nonlinear model. `NonLinearModel.fit` starts its search for optimal coefficients from **beta0**.

Properties

CoefficientCovariance

Covariance matrix of coefficient estimates.

CoefficientNames

Cell array of strings containing a label for each coefficient.

Coefficients

Table of coefficient values in a dataset array. **Coefficients** has one row for each coefficient and these columns:

- **Estimate** — Estimated coefficient value
- **SE** — Standard error of the estimate

- `tStat` — t statistic for a test that the coefficient is zero
- `pValue` — p -value for the t statistic

To obtain any of these columns as a vector, index into the property using dot notation. For example, in `mdl` the estimated coefficient vector is

```
beta = mdl.Coefficients.Estimate
```

Use `coefTest` to perform other tests on the coefficients.

Diagnostics

Dataset array with diagnostics helpful in finding outliers and influential observations. The structure contains the following fields.

Field	Meaning	Utility
Leverage	Diagonal elements of <code>HatMatrix</code>	Leverage indicates to what extent the predicted value for an observation is determined by the observed value for that observation. A value close to 1 indicates that the prediction is largely determined by that observation, with little contribution from the other observations. A value close to 0 indicates the fit is largely determined by the other observations. For a model with P coefficients and N observations, the average value of Leverage is P/N . An

NonLinearModel

Field	Meaning	Utility
		observation with Leverage larger than $2 \cdot P / N$ can be regarded as having high leverage.
CooksDistance	Cook's measure of scaled change in fitted values	CooksDistance is a measure of scaled change in fitted values. An observation with CooksDistance larger than three times the mean Cook's distance can be an outlier.
HatMatrix	Projection matrix to compute fitted from observed responses	HatMatrix is an N-by-N matrix such that $\text{Fitted} = \text{HatMatrix} \cdot Y$, where Y is the response vector and Fitted is the vector of fitted response values.

DFE

Degrees of freedom for error (residuals), equal to the number of observations minus the number of estimated coefficients.

Fitted

Vector of predicted values based on the training data. `NonLinearModel.fit` attempts to make Fitted as close as possible to the response data.

Formula

Object that represents the mathematical form of the model.

Iterative

Structure with information about the fitting process. Fields:

- `InitialCoefs` — Initial coefficient values (the `beta0` vector)
- `IterOpts` — Options included in the `Options` name-value pair for `NonLinearModel.fit`

LogLikelihood

Log likelihood of the model distribution at the response values, with mean fitted from the model, and other parameters estimated as part of the model fit.

ModelCriterion

AIC and other information criteria for comparing models. A structure with fields:

- AIC — Akaike information criterion
- AICc — Akaike information criterion corrected for sample size
- BIC — Bayesian information criterion
- CAIC — Consistent Akaike information criterion

To obtain any of these values as a scalar, index into the property using dot notation. For example, in a model `mdl`, the AIC value `aic` is:

```
aic = mdl.ModelCriterion.AIC
```

MSE

Mean squared error, a scalar that is an estimate of the variance of the error term in the model.

NumCoefficients

Number of coefficients in the fitted model, a scalar. `NumCoefficients` is the same as `NumEstimatedCoefficients` for `NonLinearModel` objects. `NumEstimatedCoefficients` is equal to the degrees of freedom for regression.

NumEstimatedCoefficients

Number of estimated coefficients in the fitted model, a scalar. `NumEstimatedCoefficients` is the same as `NumCoefficients` for `NonLinearModel` objects. `NumEstimatedCoefficients` is equal to the degrees of freedom for regression.

NumPredictors

NonLinearModel

Number of variables `NonLinearModel.fit` used as predictors for fitting.

NumVariables

Number of variables in the data. `NumVariables` is the number of variables in the original dataset when the fit is based on a dataset, or the total number of columns in the predictor matrix and response vector when the fit is based on those arrays. It includes variables, if any, that are not used as predictors or as the response.

ObservationInfo

Dataset with the same number of rows as the input data (`ds` or `X`).

Field	Description
Weights	Observation weights. Default is all 1.
Excluded	Logical value, 1 indicates an observation that you excluded from the fit with the <code>Exclude</code> name-value pair.
Missing	Logical value, 1 indicates a missing value in the input. Missing values are not used in the fit.
Subset	Logical value, 1 indicates the observation is not excluded or missing, so is used in the fit.

ObservationNames

Cell array of strings containing the names of the observations used in the fit.

- If the fit is based on a dataset containing observation names, `ObservationNames` uses those names.
- Otherwise, `ObservationNames` is an empty cell array

PredictorNames

Cell array of strings, the names of the predictors used in fitting the model.

Residuals

Dataset array containing a table of residuals, with one row for each observation and these variables.

Field	Description
Raw	Observed minus fitted values.
Pearson	Raw residuals divided by RMSE.
Standardized	Raw residuals divided by their estimated standard deviation.
Studentized	Residual divided by an independent estimate of the residual standard deviation. The residual for observation i is divided by an estimate of the error standard deviation based on all observations except for observation i .

To obtain any of these columns as a vector, index into the property using dot notation. For example, in a model `mdl`, the ordinary raw residual vector `r` is:

```
r = mdl.Residuals.Raw
```

Rows not used in the fit because of missing values (in `ObservationInfo.Missing`) contain NaN values.

Rows not used in the fit because of excluded values (in `ObservationInfo.Excluded`) contain NaN values, with the following exceptions:

- `raw` contains the difference between the observed and predicted values.
- `standardized` is the residual, standardized in the usual way.

NonLinearModel

- `studentized` matches the standardized values because this residual is not used in the estimate of the residual standard deviation.

ResponseName

String giving naming the response variable.

RMSE

Root mean squared error, a scalar that is an estimate of the standard deviation of the error term in the model.

Robust

Structure that is empty unless `NonLinearModel.fit` constructed the model using robust regression.

Field	Description
<code>WgtFun</code>	Robust weighting function, such as 'bisquare' (see <code>robustfit</code>)
<code>Tune</code>	Value specified for tuning parameter (can be [])
<code>Weights</code>	Vector of weights used in final iteration of robust fit

Rsquared

Proportion of total sum of squares explained by the model. The ordinary R-squared value relates to the SSR and SST properties:

$$\text{Rsquared} = \text{SSR}/\text{SST} = 1 - \text{SSE}/\text{SST}.$$

`Rsquared` is a structure with two fields:

- `Ordinary` — Ordinary (unadjusted) R-squared
- `Adjusted` — R-squared adjusted for the number of coefficients

To obtain any of these values as a scalar, index into the property using dot notation. For example, the adjusted R-squared value in `mdl` is

```
r2 = mdl.Rsquared.Adjusted
```

SSE

Sum of squared errors (residuals).

The Pythagorean theorem implies

$$SST = SSE + SSR.$$

SSR

Regression sum of squares, the sum of squared deviations of the fitted values from their mean.

The Pythagorean theorem implies

$$SST = SSE + SSR.$$

SST

Total sum of squares, the sum of squared deviations of `y` from `mean(y)`.

The Pythagorean theorem implies

$$SST = SSE + SSR.$$

VariableInfo

Dataset array containing metadata about `Variables`. There is one row for each term in the model, and the following columns.

NonLinearModel

Field	Description
Class	String giving variable class, such as 'double'
Range	Cell array giving variable range: <ul style="list-style-type: none">• Continuous variable — Two-element vector $[min, max]$, the minimum and maximum values• Categorical variable — Cell array of distinct variable values
InModel	Logical vector, where true indicates the variable is in the model
IsCategorical	Logical vector, where true indicates a categorical variable

VariableNames

Cell array of strings containing names of the variables in the fit.

- If the fit is based on a dataset, this property provides the names of the variables in that dataset.
- If the fit is based on a predictor matrix and response vector, `VariableNames` is the values in the `VarNames` name-value pair of the fitting method.
- Otherwise the variables have the default fitting names.

Variables

Dataset array containing the data, both observations and responses, that the fitting function used to construct the fit. If the fit is based on a dataset array, `Variables` is a copy of that dataset. Otherwise, `Variables` is a dataset created from the input data matrix X and response vector y .

Methods

coefCI	Confidence intervals of coefficient estimates of nonlinear regression model
coefTest	Linear hypothesis test on nonlinear regression model coefficients
disp	Display nonlinear regression model
feval	Evaluate nonlinear regression model prediction
fit	Fit nonlinear regression model
plotDiagnostics	Plot diagnostics of nonlinear regression model
plotResiduals	Plot residuals of nonlinear regression model
plotSlice	Plot of slices through fitted nonlinear regression surface
predict	Predict response of nonlinear regression model
random	Simulate responses for nonlinear regression model

Definitions

Hat Matrix

The *hat matrix* H is defined in terms of the data matrix X and the Jacobian matrix J :

$$J_{i,j} = \left. \frac{\partial f}{\partial \beta_j} \right|_{x_i, \beta}$$

NonLinearModel

Here f is the nonlinear model function, and β is the vector of model coefficients.

The Hat Matrix H is

$$H = J(J^T J)^{-1} J^T.$$

The diagonal elements H_{ii} satisfy

$$0 \leq h_{ii} \leq 1$$

$$\sum_{i=1}^n h_{ii} = p,$$

where n is the number of observations (rows of X), and p is the number of coefficients in the regression model.

Leverage

The *leverage* of observation i is the value of the i th diagonal term of the hat matrix H_{ii} . Because the sum of the leverage values is p (the number of coefficients in the regression model), an observation i can be considered to be an outlier if its leverage substantially exceeds p/n , where n is the number of observations.

Cook's Distance

The Cook's distance D_i of observation i is

$$D_i = \frac{\sum_{j=1}^n (\hat{y}_j - \hat{y}_{j(i)})^2}{p \text{MSE}},$$

where

- \hat{y}_j is the j th fitted response value.

- $\hat{y}_{j(i)}$ is the j th fitted response value, where the fit does not include observation i .
- MSE is the mean squared error.
- p is the number of coefficients in the regression model.

Cook's distance is algebraically equivalent to the following expression:

$$D_i = \frac{r_i^2}{pMSE} \left(\frac{h_{ii}}{(1-h_{ii})^2} \right),$$

where e_i is the i th residual.

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Nonlinear Model

Create a nonlinear model for auto mileage based on the `carbig` data. Predict the mileage of an average car.

Load the data and create a nonlinear model.

```
load carbig
X = [Horsepower,Weight];
y = MPG;
modelfun = @(b,x)b(1) + b(2)*x(:,1).^b(3) + ...
    b(4)*x(:,2).^b(5);
beta0 = [-50 500 -1 500 -1];
mdl = NonLinearModel.fit(X,y,modelfun,beta0)
```

```
mdl =
```

```
Nonlinear regression model:
y ~ b1 + b2*x1^b3 + b4*x2^b5
```

NonLinearModel

Estimated Coefficients:

	Estimate	SE	tStat	pValue
b1	-49.383	119.97	-0.41164	0.68083
b2	376.43	567.05	0.66384	0.50719
b3	-0.78193	0.47168	-1.6578	0.098177
b4	422.37	776.02	0.54428	0.58656
b5	-0.24127	0.48325	-0.49926	0.61788

Number of observations: 392, Error degrees of freedom: 387

Root Mean Squared Error: 3.96

R-Squared: 0.745, Adjusted R-Squared 0.743

F-statistic vs. constant model: 283, p-value = 1.79e-113

Find the predicted mileage of an average auto. The data contain some observations with NaN, so compute the mean using `nanmean`.

```
Xnew = nanmean(X)
```

```
Xnew =  
1.0e+03 *  
0.1051 2.9794
```

```
MPGnew = predict(md1,Xnew)
```

```
MPGnew =  
21.8073
```

See Also

[GeneralizedLinearModel](#) | [LinearModel](#) | [nlinfitNonLinearModel.fit](#) | [NonLinearModel.predict](#) |

Related Examples

- “Nonlinear Regression Workflow” on page 9-210

Concepts

- “Nonlinear Regression” on page 9-196

Purpose

Normal cumulative distribution function

Syntax

```
P = normcdf(X,mu,sigma)
[P,PLO,PUP] = normcdf(X,mu,sigma,pcov,alpha)
```

Description

`P = normcdf(X,mu,sigma)` computes the normal cdf at each of the values in `X` using the corresponding mean `mu` and standard deviation `sigma`. `X`, `mu`, and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `sigma` must be positive.

`[P,PLO,PUP] = normcdf(X,mu,sigma,pcov,alpha)` produces confidence bounds for `P` when the input parameters `mu` and `sigma` are estimates. `pcov` is the covariance matrix of the estimated parameters. `alpha` specifies 100(1 - `alpha`)% confidence bounds. The default value of `alpha` is 0.05. `PLO` and `PUP` are arrays of the same size as `P` containing the lower and upper confidence bounds.

The function `normcdf` computes confidence bounds for `P` using a normal approximation to the distribution of the estimate

$$\frac{X - \hat{\mu}}{\hat{\sigma}}$$

and then transforming those bounds to the scale of the output `P`. The computed bounds give approximately the desired confidence level when you estimate `mu`, `sigma`, and `pcov` from large samples, but in smaller samples other methods of computing the confidence bounds might be more accurate.

The normal cdf is

$$p = F(x | \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{(t-\mu)^2}{2\sigma^2}} dt$$

The result, `p`, is the probability that a single observation from a normal distribution with parameters `μ` and `σ` will fall in the interval $(-\infty, x]$.

normcdf

The *standard normal* distribution has $\mu = 0$ and $\sigma = 1$.

Examples

What is the probability that an observation from a standard normal distribution will fall on the interval $[-1 \ 1]$?

```
p = normcdf([-1 1]);  
p(2) - p(1)  
ans =  
    0.6827
```

More generally, about 68% of the observations from a normal distribution fall within one standard deviation, σ , of the mean, μ .

See Also

[cdf](#) | [normpdf](#) | [norminv](#) | [normstat](#) | [normfit](#) | [normlike](#) | [normrnd](#)

How To

- “Normal Distribution” on page B-96

Purpose

Normal parameter estimates

Syntax

```
[muhat,sigmahat] = normfit(data)
[muhat,sigmahat,muci,sigmaci] = normfit(data)
[muhat,sigmahat,muci,sigmaci] = normfit(data,alpha)
[...] = normfit(data,alpha,censoring)
[...] = normfit(data,alpha,censoring,freq)
[...] = normfit(data,alpha,censoring,freq,options)
```

Description

`[muhat,sigmahat] = normfit(data)` returns an estimate of the mean μ in `muhat`, and an estimate of the standard deviation σ in `sigmahat`, of the normal distribution given the data in `data`.

`[muhat,sigmahat,muci,sigmaci] = normfit(data)` returns 95% confidence intervals for the parameter estimates on the mean and standard deviation in the arrays `muci` and `sigmaci`, respectively. The first row of `muci` contains the lower bounds of the confidence intervals for μ the second row contains the upper bounds. The first row of `sigmaci` contains the lower bounds of the confidence intervals for σ , and the second row contains the upper bounds.

`[muhat,sigmahat,muci,sigmaci] = normfit(data,alpha)` returns $100(1 - \alpha)$ % confidence intervals for the parameter estimates, where `alpha` is a value in the range `[0 1]` specifying the width of the confidence intervals. By default, `alpha` is 0.05, which corresponds to 95% confidence intervals.

`[...] = normfit(data,alpha,censoring)` accepts a Boolean vector, `censoring`, of the same size as `data`, which is 1 for observations that are right-censored and 0 for observations that are observed exactly. `data` must be a vector in order to pass in the argument `censoring`.

`[...] = normfit(data,alpha,censoring,freq)` accepts a frequency vector, `freq`, of the same size as `data`. Typically, `freq` contains integer frequencies for the corresponding elements in `data`, but can contain any nonnegative values. Pass in `[]` for `alpha`, `censoring`, or `freq` to use their default values.

normfit

[...] = normfit(data,alpha,censoring,freq,options) accepts a structure, options, that specifies control parameters for the iterative algorithm the function uses to compute maximum likelihood estimates when there is censoring. The normal fit function accepts an options structure which you can create using the function statset. Enter statset('normfit') to see the names and default values of the parameters that normfit accepts in the options structure. See the reference page for statset for more information about these options.

Note With no censoring, normfit computes `sigmahat` using the square root of the unbiased estimator of the variance. With censoring, `sigmahat` is the maximum likelihood estimate.

Examples

In this example the data is a two-column random normal matrix. Both columns have $\mu = 10$ and $\sigma = 2$. Note that the confidence intervals below contain the "true values."

```
data = normrnd(10,2,100,2);
[mu,sigma,muci,sigmaci] = normfit(data)
mu =
    10.1455    10.0527
sigma =
    1.9072    2.1256
muci =
    9.7652    9.6288
    10.5258    10.4766
sigmaci =
    1.6745    1.8663
    2.2155    2.4693
```

See Also

mle | normlike | normpdf | normcdf | norminv | normstat | normrnd

How To

- “Normal Distribution” on page B-96

Purpose

Normal inverse cumulative distribution function

Syntax

```
X = norminv(P,mu,sigma)
[X,XLO,XUP] = norminv(P,mu,sigma,pcov,alpha)
```

Description

`X = norminv(P,mu,sigma)` computes the inverse of the normal cdf using the corresponding mean `mu` and standard deviation `sigma` at the corresponding probabilities in `P`. `P`, `mu`, and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `sigma` must be positive, and the values in `P` must lie in the interval `[0 1]`.

`[X,XLO,XUP] = norminv(P,mu,sigma,pcov,alpha)` produces confidence bounds for `X` when the input parameters `mu` and `sigma` are estimates. `pcov` is the covariance matrix of the estimated parameters. `alpha` specifies `100(1 - alpha)%` confidence bounds. The default value of `alpha` is `0.05`. `XLO` and `XUP` are arrays of the same size as `X` containing the lower and upper confidence bounds.

The function `norminv` computes confidence bounds for `P` using a normal approximation to the distribution of the estimate

$$\hat{\mu} + \hat{\sigma}q$$

where q is the P th quantile from a normal distribution with mean 0 and standard deviation 1. The computed bounds give approximately the desired confidence level when you estimate `mu`, `sigma`, and `pcov` from large samples, but in smaller samples other methods of computing the confidence bounds may be more accurate.

The normal inverse function is defined in terms of the normal cdf as

$$x = F^{-1}(p | \mu, \sigma) = \{x : F(x | \mu, \sigma) = p\}$$

where

norminv

$$p = F(x | \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{(t-\mu)^2}{2\sigma^2}} dt$$

The result, x , is the solution of the integral equation above where you supply the desired probability, p .

Examples

Find an interval that contains 95% of the values from a standard normal distribution.

```
x = norminv([0.025 0.975],0,1)
x =
-1.9600  1.9600
```

Note that the interval x is not the only such interval, but it is the shortest.

```
x1 = norminv([0.01 0.96],0,1)
x1 =
-2.3263  1.7507
```

The interval $x1$ also contains 95% of the probability, but it is longer than x .

See Also

[icdf](#) | [normcdf](#) | [normpdf](#) | [normstat](#) | [normfit](#) | [normlike](#) | [normrnd](#)

How To

- “Normal Distribution” on page B-96

Purpose	Normal negative log-likelihood
Syntax	<pre>nlogL = normlike(params,data) [nlogL,AVAR] = normlike(params,data) [...] = normlike(param,data,censoring) [...] = normlike(param,data,censoring,freq)</pre>
Description	<p><code>nlogL = normlike(params,data)</code> returns the negative of the normal log-likelihood function. <code>params(1)</code> is the mean, <code>mu</code>, and <code>params(2)</code> is the standard deviation, <code>sigma</code>.</p> <p><code>[nlogL,AVAR] = normlike(params,data)</code> also returns the inverse of Fisher's information matrix, <code>AVAR</code>. If the input parameter values in <code>params</code> are the maximum likelihood estimates, the diagonal elements of <code>AVAR</code> are their asymptotic variances. <code>AVAR</code> is based on the observed Fisher's information, not the expected information.</p> <p><code>[...] = normlike(param,data,censoring)</code> accepts a Boolean vector, <code>censoring</code>, of the same size as <code>data</code>, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.</p> <p><code>[...] = normlike(param,data,censoring,freq)</code> accepts a frequency vector, <code>freq</code>, of the same size as <code>data</code>. The vector <code>freq</code> typically contains integer frequencies for the corresponding elements in <code>data</code>, but can contain any nonnegative values. Pass in <code>[]</code> for <code>censoring</code> to use its default value.</p> <p><code>normlike</code> is a utility function for maximum likelihood estimation.</p>
See Also	<code>normfit</code> <code>normpdf</code> <code>normcdf</code> <code>norminv</code> <code>normstat</code> <code>normrnd</code>
How To	<ul style="list-style-type: none">• “Normal Distribution” on page B-96

normpdf

Purpose Normal probability density function

Syntax
`Y = normpdf(X,mu,sigma)`
`Y = normpdf(X)`
`Y = normpdf(X,mu)`

Description `Y = normpdf(X,mu,sigma)` computes the pdf at each of the values in `X` using the normal distribution with mean `mu` and standard deviation `sigma`. `X`, `mu`, and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `sigma` must be positive.

The normal pdf is

$$y = f(x | \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

The *likelihood function* is the pdf viewed as a function of the parameters. Maximum likelihood estimators (MLEs) are the values of the parameters that maximize the likelihood function for a fixed value of `x`.

The *standard normal* distribution has $\mu = 0$ and $\sigma = 1$.

If `x` is standard normal, then `xσ + μ` is also normal with mean μ and standard deviation σ . Conversely, if `y` is normal with mean μ and standard deviation σ , then `x = (y-μ) / σ` is standard normal.

`Y = normpdf(X)` uses the standard normal distribution (`mu = 0`, `sigma = 1`).

`Y = normpdf(X,mu)` uses the normal distribution with unit standard deviation (`sigma = 1`).

Examples

```
mu = [0:0.1:2];  
[y i] = max(normpdf(1.5,mu,1));  
MLE = mu(i)  
MLE =
```


1.5000

See Also

pdf | normcdf | norminv | normstat | normfit | normlike | normrnd
| mvnpdf

How To

- “Normal Distribution” on page B-96

normplot

Purpose Normal probability plot

Syntax `h = normplot(X)`

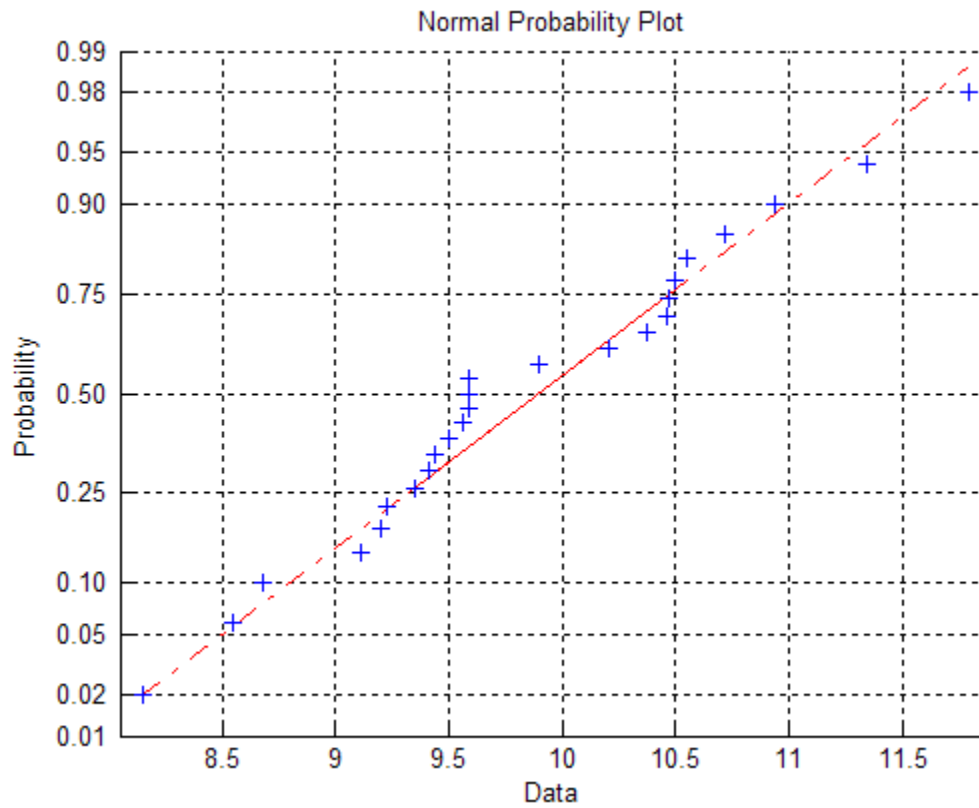
Description `h = normplot(X)` displays a normal probability plot of the data in `X`. For matrix `X`, `normplot` displays a line for each column of `X`. `h` is a handle to the plotted lines.

The plot has the sample data displayed with the plot symbol '+' . Superimposed on the plot is a line joining the first and third quartiles of each column of `X` (a robust linear fit of the sample order statistics.) This line is extrapolated out to the ends of the sample to help evaluate the linearity of the data.

The purpose of a normal probability plot is to graphically assess whether the data in `X` could come from a normal distribution. If the data are normal the plot will be linear. Other distribution types will introduce curvature in the plot. `normplot` uses midpoint probability plotting positions. Use `probplot` when the data included censored observations.

Examples Generate a normal sample and a normal probability plot of the data.

```
x = normrnd(10,1,25,1);  
normplot(x)
```

**See Also**

`cdfplot` | `wblplot` | `probplot` | `hist` | `normfit` | `norminv` | `normpdf`
| `normspec` | `normstat` | `normcdf` | `normrnd` | `normlike`

How To

- “Normal Distribution” on page B-96

normrnd

Purpose Normal random numbers

Syntax
`R = normrnd(mu,sigma)`
`R = normrnd(mu,sigma,m,n,...)`
`R = normrnd(mu,sigma,[m,n,...])`

Description `R = normrnd(mu,sigma)` generates random numbers from the normal distribution with mean parameter `mu` and standard deviation parameter `sigma`. `mu` and `sigma` can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of `R`. A scalar input for `mu` or `sigma` is expanded to a constant array with the same dimensions as the other input.

`R = normrnd(mu,sigma,m,n,...)` or `R = normrnd(mu,sigma,[m,n,...])` generates an `m`-by-`n`-by-... array. The `mu`, `sigma` parameters can each be scalars or arrays of the same size as `R`.

Examples

```
n1 = normrnd(1:6,1./(1:6))
n1 =
    2.1650    2.3134    3.0250    4.0879    4.8607    6.2827

n2 = normrnd(0,1,[1 5])
n2 =
    0.0591    1.7971    0.2641    0.8717   -1.4462

n3 = normrnd([1 2 3;4 5 6],0.1,2,3)
n3 =
    0.9299    1.9361    2.9640
    4.1246    5.0577    5.9864
```

See Also `random` | `normpdf` | `normcdf` | `norminv` | `normstat` | `normfit` | `normlike` | `mvnrnd` | `lognrnd`

How To • “Normal Distribution” on page B-96

Purpose Normal density plot between specifications

Syntax

```
normspec(specs)
normspec(specs,mu,sigma)
normspec(specs,mu,sigma,region)
p = normspec(...)
[p,h] = normspec(...)
```

Description

`normspec(specs)` plots the standard normal density, shading the portion inside the specification limits given by the two-element vector `specs`. Set `specs(1)` to `-Inf` if there is no lower limit; set `specs(2)` to `Inf` if there is no upper limit.

`normspec(specs,mu,sigma)` shades the portion inside the specification limits of a normal density with parameters `mu` and `sigma`. The defaults are `mu = 0` and `sigma = 1`.

`normspec(specs,mu,sigma,region)` shades the *region* either 'inside' or 'outside' the specification limits. The default is 'inside'.

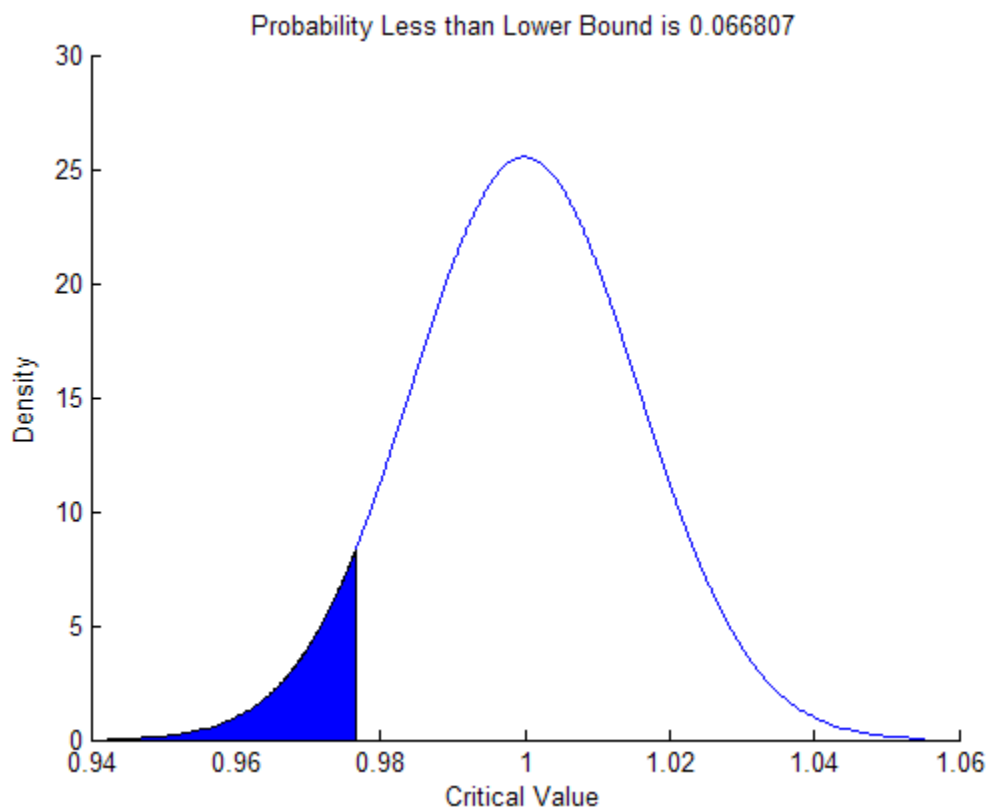
`p = normspec(...)` also returns the probability, `p`, of the shaded area.

`[p,h] = normspec(...)` also returns a handle `h` to the line objects.

Examples

A production process fills cans of paint. The average amount of paint in any can is 1 gallon, but variability in the process produces a standard deviation of 2 ounces (2/128 gallons). What is the probability that cans will be filled under specification by 3 or more ounces?

```
p = normspec([1-3/128,Inf],1,2/128,'outside')
p =
    0.0668
```



See Also

`capaplot` | `histfit`

How To

- “Normal Distribution” on page B-96

Purpose Normal mean and variance

Syntax `[M,V] = normstat(mu,sigma)`

Description `[M,V] = normstat(mu,sigma)` returns the mean of and variance for the normal distribution using the corresponding mean `mu` and standard deviation `sigma`. `mu` and `sigma` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `M` and `V`. A scalar input for `mu` or `sigma` is expanded to a constant array with the same dimensions as the other input.

The mean of the normal distribution with parameters μ and σ is μ , and the variance is σ^2 .

Examples

```
n = 1:5;
[m,v] = normstat(n'*n,n'*n)
m =
     1     2     3     4     5
     2     4     6     8    10
     3     6     9    12    15
     4     8    12    16    20
     5    10    15    20    25

v =
     1     4     9    16    25
     4    16    36    64   100
     9    36    81   144   225
    16    64   144   256   400
    25   100   225   400   625
```

See Also `normpdf` | `normcdf` | `norminv` | `normfit` | `normlike` | `normrnd`

How To • “Normal Distribution” on page B-96

piecewisedistribution.nsegments

Purpose Number of segments

Syntax `n = nsegments(obj)`

Description `n = nsegments(obj)` returns the number of segments `n` in the piecewise distribution object `obj`.

Examples Fit Pareto tails to a t distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);  
obj = paretotails(t,0.1,0.9);
```

```
n = nsegments(obj)
```

```
n =  
    3
```

See Also `paretotails` | `boundary` | `segment`

TreeBagger.NTrees property

Purpose Number of decision trees in ensemble

Description The NTrees property is a scalar equal to the number of decision trees in the ensemble.

See Also Trees

ProbDistParametric.NumParams property

Purpose	Read-only value specifying number of parameters of ProbDistParametric object
Description	NumParams is a read-only property of the ProbDistParametric class. NumParams is a value specifying the number of parameters of a distribution represented by a ProbDistParametric object.
Values	This value is an integer that counts both the specified parameters and parameters that are fit to the data. Use this information to view and compare the number of parameters supplied to create distributions.

Purpose Number of elements in dataset array

Syntax `n = numel(A)`
 `n = numel(A, varargin)`

Description `n = numel(A)` returns 1. To find the number of elements, `n`, in the dataset array `A`, use `prod(size(A))` or `numel(A, ':', ':')`.

`n = numel(A, varargin)` returns the number of subscripted elements, `n`, in `A(index1, index2, ..., indexn)`, where `varargin` is a cell array whose elements are `index1, index2, ... indexn`.

See Also `length` | `size`

categorical.numel

Purpose Number of elements in categorical array

Syntax `n = numel(A)`
 `n = numel(A, varargin)`

Description `n = numel(A)` returns the number of elements in the categorical array `A`.

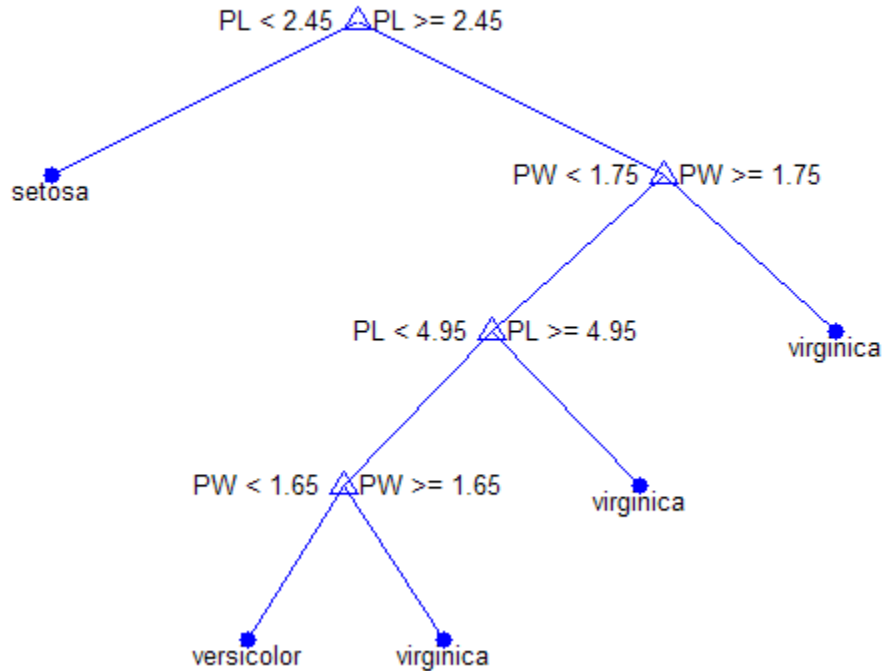
`n = numel(A, varargin)` returns the number of subscripted elements, `n`, in `A(index1, index2, ..., indexN)`, where `varargin` is a cell array whose elements are `index1, index2, ... indexN`.

See Also `size`

Purpose	Number of nodes
Syntax	<code>n = numnodes(t)</code>
Description	<code>n = numnodes(t)</code> returns the number of nodes <code>n</code> in the tree <code>t</code> .
Examples	<p>Create a classification tree for Fisher's iris data:</p> <pre>load fisheriris; t = classregtree(meas,species,... 'names',{'SL' 'SW' 'PL' 'PW'}) t= Decision tree for classification 1 if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa 2 class = setosa 3 if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor 4 if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor 5 class = virginica 6 if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor 7 class = virginica 8 class = versicolor 9 class = virginica view(t)</pre>

classregtree.numnodes

Click to display: Magnification: Pruning level:



n = numnodes(t)

n =

9

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree

cvpartition.NumTestSets property

Purpose

Number of test sets

Description

Value is the number of folds in partitions of type 'kfold' and 'leaveout'.

Value is 1 in partitions of type 'holdout' and 'resubstitution'.

TreeBagger.NVarToSample property

Purpose Number of variables for random feature selection

Description The `NVarToSample` property specifies the number of predictor or feature variables to select at random for each decision split. By default, it is set to the square root of the total number of variables for classification and one third of the total number of variables for regression. Setting this argument to any valid value except 'all' invokes Breiman's "random forest" algorithm.

See Also `classregtree`

dataset.ObsNames property

Purpose

Cell array of nonempty, distinct strings giving names of observations in data set

Description

A cell array of nonempty, distinct strings giving the names of the observations in the data set. This property may be empty, but if not empty, the number of strings must equal the number of observations.

optimalleaforder

Purpose Optimal leaf ordering for hierarchical clustering

Syntax
`leafOrder = optimalleaforder(tree,D)`
`leafOrder = optimalleaforder(tree,D,Name,Value)`

Description `leafOrder = optimalleaforder(tree,D)` returns an optimal leaf ordering for the hierarchical binary cluster tree, `tree`, using the distances, `D`. An optimal leaf ordering of a binary tree maximizes the sum of the similarities between adjacent leaves by flipping tree branches without dividing the clusters.

`leafOrder = optimalleaforder(tree,D,Name,Value)` returns the optimal leaf ordering using one or more name-value pair arguments.

Input Arguments

tree - Hierarchical binary cluster tree

matrix returned by `linkage`

Hierarchical binary cluster tree, specified as an $(M - 1)$ -by-3 matrix that you generate using `linkage`, where M is the number of leaves.

D - Distances

matrix | vector

Distances for determining similarities between leaves, specified as a matrix or vector of distances. For example, you can generate distances using `pdist`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Example: `'Criteria', 'group', 'Transformation', 'inverse'` specifies that the sum of similarities be maximized between every leaf

and all other leaves in adjacent clusters, using an inverse similarity transformation.

Criteria - Optimization criterion

'adjacent' (default) | 'group'

Optimization criterion for determining an optimal leaf ordering, specified as the comma-separated pair consisting of 'criteria' and one of these strings:

'adjacent'	Maximize the sum of similarities between adjacent leaves.
'group'	Maximize the sum of similarities between every leaf and all other leaves in the adjacent clusters at the same level of the dendrogram.

Example: 'Criteria', 'group'

Data Types

char

Transformation - Method for transforming distances to similarities

'linear' (default) | 'inverse' | function handle

Method for transforming distances to similarities, specified as the comma-separated pair consisting of 'Transformation' and one of 'linear', 'inverse', or a function handle.

Let $d_{i,j}$ and $Sim_{i,j}$ denote the distance and similarity between leaves i and j , respectively. The included similarity transformations are:

'linear'	$Sim_{i,j} = \max_{i,j} (d_{i,j}) - d_{i,j}$
'inverse'	$Sim_{i,j} = 1/d_{i,j}$

To use a custom transformation function, specify a handle to a function that accepts a matrix of distances, D, and returns a matrix of similarities, S. The function should be monotonic decreasing in the

optimalleaforder

range of distance values. S must have the same size as D , with $S(i, j)$ being the similarity computed based on $D(i, j)$.

Example: 'Transformation',@myTransform

Data Types

char | function_handle

Output Arguments

leafOrder - Optimal leaf order

vector

Optimal leaf order, returned as a length- M vector, where M is the number of leaves. `leafOrder` is a permutation of the vector $1:M$, giving an optimal leaf ordering based on the specified distances and similarity transformation.

Examples

Plot Dendrogram With Optimal Leaf Order

Create a hierarchical binary cluster tree using `linkage`. Then, compare the dendrogram plot with the default ordering to a dendrogram with an optimal leaf ordering.

Generate sample data.

```
rng('default') % For reproducibility
X = rand(10,2);
```

Create a distance vector and a hierarchical binary clustering tree. Use the distances and clustering tree to determine an optimal leaf order.

```
D = pdist(X);
tree = linkage(D, 'average');
leafOrder = optimalleaforder(tree,D);
```

Plot the dendrogram with the default ordering and the dendrogram with the optimal leaf ordering.

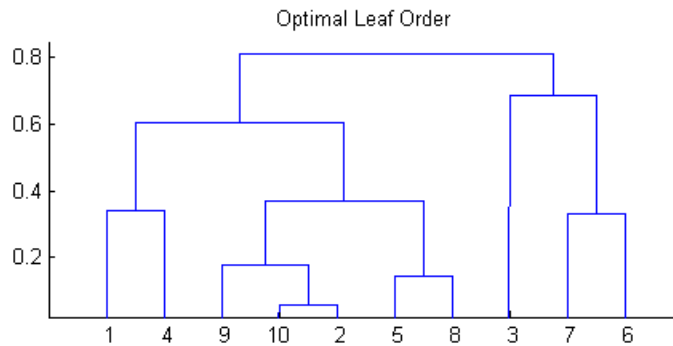
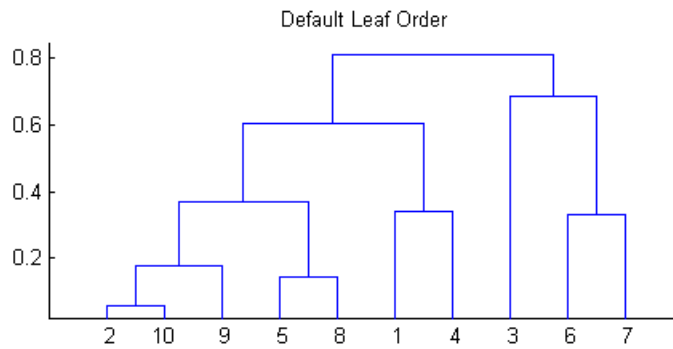
```
figure()
subplot(2,1,1)
dendrogram(tree)
```

```

title('Default Leaf Order')

subplot(2,1,2)
dendrogram(tree,'reorder',leafOrder)
title('Optimal Leaf Order')

```



The order of the leaves in the bottom figure corresponds to the elements in `leafOrder`.

`leafOrder`

`leafOrder =`

optimalleaforder

```
1 4 9 10 2 5 8 3 7 6
```

Optimal Leaf Order Using Inverse Distance Similarity

Generate sample data.

```
rng('default') % For reproducibility  
X = rand(10,2);
```

Create a distance vector and a hierarchical binary clustering tree.

```
D = pdist(X);  
tree = linkage(D,'average');
```

Use the inverse distance similarity transformation to determine an optimal leaf order.

```
leafOrder = optimalleaforder(tree,D,'Transformation','inverse')
```

```
leafOrder =
```

```
1 4 9 10 2 5 8 3 7 6
```

References

[1] Bar-Joseph, Z., Gifford, D.K., and Jaakkola, T.S. (2001). Fast optimal leaf ordering for hierarchical clustering. *Bioinformatics* 17, Suppl 1:S22–9. PMID: 11472989.

See Also

[dendrogram](#) | [linkage](#) | [pdist](#)

Purpose Out-of-bag classification edge

Syntax
edge = oobEdge(ens)
edge = oobEdge(ens,Name,Value)

Description
edge = oobEdge(ens) returns out-of-bag classification edge for ens.
edge = oobEdge(ens,Name,Value) computes classification edge with additional options specified by one or more Name,Value pair arguments. You can specify several name-value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

Input Arguments
ens
A classification bagged ensemble, constructed with fitensemble.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

learners

Indices of weak learners in the ensemble ranging from 1 to ens.NTrained. oobEdge uses only these learners for calculating loss.

Default: 1:NTrained

mode

String representing the meaning of the output L:

- 'ensemble' — L is a scalar value, the loss for the entire ensemble.

ClassificationBaggedEnsemble.oobEdge

- 'individual' — L is a vector with one element per trained learner.
- 'cumulative' — L is a vector in which element J is obtained by using learners 1:J from the input list of learners.

Default: 'ensemble'

Output Arguments

edge

Classification edge, a weighted average of the classification margin.

Definitions

Edge

The *edge* is the weighted mean value of the classification margin. The weights are the class probabilities in `ens.Prior`.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `ens.X`.

Out of Bag

Bagging, which stands for “bootstrap aggregation”, is a type of ensemble learning. To bag a weak learner such as a decision tree on a dataset, `fitensemble` generates many bootstrap replicas of the dataset and grows decision trees on these replicas. `fitensemble` obtains each bootstrap replica by randomly selecting N observations out of N with replacement, where N is the dataset size. To find the predicted response of a trained ensemble, `predict` take an average over predictions from individual trees.

Drawing N out of N observations with replacement omits on average 37% ($1/e$) of observations for each decision tree. These are "out-of-bag" observations. For each observation, `oobLoss` estimates the out-of-bag prediction by averaging over predictions from all trees in the ensemble for which this observation is out of bag. It then compares the computed

prediction against the true response for this observation. It calculates the out-of-bag error by comparing the out-of-bag predicted responses against the true responses for all observations used for training. This out-of-bag average is an unbiased estimator of the true ensemble error.

Examples

Find the out-of-bag edge for a bagged ensemble from the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'Bag',100,...
    'Tree','type','classification');
edge = oobEdge(ens)

edge =
    0.8730
```

See Also

[oobMargin](#) | [oobPredict](#) | [oobLoss](#)

TreeBagger.oobError

Purpose Out-of-bag error

Syntax
`err = oobError(B)`
`err = oobError(B, 'param1', val1, 'param2', val2, ...)`

Description `err = oobError(B)` computes the misclassification probability (for classification trees) or mean squared error (for regression trees) for out-of-bag observations in the training data, using the trained bagger `B`. `err` is a vector of length `NTrees`, where `NTrees` is the number of trees in the ensemble.

`err = oobError(B, 'param1', val1, 'param2', val2, ...)` specifies optional parameter name/value pairs:

`'mode'` String indicating how `oobError` computes errors. If set to `'cumulative'` (default), the method computes cumulative errors and `err` is a vector of length `NTrees`, where the first element gives error from `trees(1)`, second element gives error from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to `'individual'`, `err` is a vector of length `NTrees`, where each element is an error from each tree in the ensemble. If set to `'ensemble'`, `err` is a scalar showing the cumulative error for the entire ensemble.

`'trees'` Vector of indices indicating what trees to include in this calculation. By default, this argument is set to `'all'` and the method uses all trees. If `'trees'` is a numeric vector, the method returns a vector of length `NTrees` for `'cumulative'` and `'individual'` modes, where `NTrees` is the number of elements in the input vector, and a scalar for `'ensemble'` mode. For example, in the `'cumulative'` mode, the

first element gives error from `trees(1)`, the second element gives error from `trees(1:2)` etc.

'treeweights' Vector of tree weights. This vector must have the same length as the 'trees' vector. `oobError` uses these weights to combine output from the specified trees by taking a weighted average instead of the simple nonweighted majority vote. You cannot use this argument in the 'individual' mode.

See Also

`CompactTreeBagger.error`

TreeBagger.OOBIndices property

Purpose Indicator matrix for out-of-bag observations

Description The `OOBIndices` property is a logical array of size `Nobs-by-NTrees` where `Nobs` is the number of observations in the training data and `NTrees` is the number of trees in the ensemble. The (I, J) element is true if observation `I` is out-of-bag for tree `J` and false otherwise. In other words, a true value means observation `I` was not selected for the training data used to grow tree `J`.

See Also `classregtree`

TreeBagger.OOBInstanceWeight property

Purpose

Count of out-of-bag trees for each observation

Description

The `OOBInstanceWeight` property is a numeric array of size `Nobs-by-1` containing the number of trees used for computing out-of-bag response for each observation. `Nobs` is the number of observations in the training data used to create the ensemble.

ClassificationBaggedEnsemble.oobLoss

Purpose Out-of-bag classification error

Syntax
L = oobloss(ens)
L = oobloss(ens,Name,Value)

Description L = oobloss(ens) returns the classification error for ens computed for out-of-bag data.

L = oobloss(ens,Name,Value) computes error with additional options specified by one or more Name,Value pair arguments. You can specify several name-value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

Input Arguments

ens
A classification bagged ensemble, constructed with fitensemble.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

learners

Indices of weak learners in the ensemble ranging from 1 to NTrained. oobLoss uses only these learners for calculating loss.

Default: 1:NTrained

lossfun

Function handle or string representing a loss function. Built-in loss functions:

- 'binodeviance' — See “Loss Functions” on page 20-1606
- 'classiferror' — Fraction of misclassified data

- 'exponential' — See “Loss Functions” on page 20-1606

You can write your own loss function in the syntax described in “Loss Functions” on page 20-1606.

Default: 'classiferror'

mode

String representing the meaning of the output L:

- 'ensemble' — L is a scalar value, the loss for the entire ensemble.
- 'individual' — L is a vector with one element per trained learner.
- 'cumulative' — L is a vector in which element J is obtained by using learners 1:J from the input list of learners.

Default: 'ensemble'

Output Arguments

L

Classification error of the out-of-bag observations, a scalar. L can be a vector, or can represent a different quantity, depending on the name-value settings.

Definitions

Out of Bag

Bagging, which stands for “bootstrap aggregation”, is a type of ensemble learning. To bag a weak learner such as a decision tree on a dataset, `fitensemble` generates many bootstrap replicas of the dataset and grows decision trees on these replicas. `fitensemble` obtains each bootstrap replica by randomly selecting N observations out of N with replacement, where N is the dataset size. To find the predicted response of a trained ensemble, `predict` take an average over predictions from individual trees.

ClassificationBaggedEnsemble.oobLoss

Drawing N out of N observations with replacement omits on average 37% ($1/e$) of observations for each decision tree. These are "out-of-bag" observations. For each observation, `oobLoss` estimates the out-of-bag prediction by averaging over predictions from all trees in the ensemble for which this observation is out of bag. It then compares the computed prediction against the true response for this observation. It calculates the out-of-bag error by comparing the out-of-bag predicted responses against the true responses for all observations used for training. This out-of-bag average is an unbiased estimator of the true ensemble error.

Loss Functions

The built-in loss functions are:

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'classiferror' — Fraction of misclassified data, weighted by w .
- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

To write your own loss function, create a function file of the form

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of X .
- K is the number of classes in `tree`, represented in `tree.ClassNames`.
- C is an N -by- K logical matrix, with one true per row for the true class. The index for each class is its position in `tree.ClassNames`.

ClassificationBaggedEnsemble.oobLoss

- S is an N -by- K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from `predict`.
- W is a numeric vector with N elements, the observation weights.
- $COST$ is a K -by- K numeric matrix of misclassification costs. The default `'classiferror'` cost function uses a cost of 0 for correct classification, and 1 for misclassification. In other words, `'classiferror'` uses $COST = \text{ones}(K) - \text{eye}(K)$.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

Examples

Find the out-of-bag error for a bagged ensemble from the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'Bag',100,...
    'Tree','type','classification');
L = oobLoss(ens)
```

```
L =
    0.0467
```

See Also

`loss` | `oobEdge` | `oobMargin` | `oobPredict`

RegressionBaggedEnsemble.oobLoss

Purpose Out-of-bag regression error

Syntax
L = oobLoss(ens)
L = oobLoss(ens,Name,Value)

Description L = oobLoss(ens) returns the mean squared error for ens computed for out-of-bag data.

L = oobLoss(ens,Name,Value) computes error with additional options specified by one or more Name,Value pair arguments. You can specify several name-value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

Input Arguments

ens
A regression bagged ensemble, constructed with fitensemble.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

learners

Indices of weak learners in the ensemble ranging from 1 to NTrained. oobLoss uses only these learners for calculating loss.

Default: 1:NTrained

lossfun

Function handle for loss function, or the string 'mse', meaning mean squared error. If you pass a function handle fun, oobLoss calls it as

FUN(Y,Yfit,W)

where Y , Y_{fit} , and W are numeric vectors of the same length. Y is the observed response, Y_{fit} is the predicted response, and W is the observation weights.

Default: 'mse'

mode

String representing the meaning of the output L :

- 'ensemble' — L is a scalar value, the loss for the entire ensemble.
- 'individual' — L is a vector with one element per trained learner.
- 'cumulative' — L is a vector in which element J is obtained by using learners $1:J$ from the input list of learners.

Default: 'ensemble'

Output Arguments

L

Mean squared error of the out-of-bag observations, a scalar. L can be a vector, or can represent a different quantity, depending on the name-value settings.

Definitions

Out of Bag

Bagging, which stands for “bootstrap aggregation”, is a type of ensemble learning. To bag a weak learner such as a decision tree on a dataset, `fitensemble` generates many bootstrap replicas of the dataset and grows decision trees on these replicas. `fitensemble` obtains each bootstrap replica by randomly selecting N observations out of N with replacement, where N is the dataset size. To find the predicted response of a trained ensemble, `predict` take an average over predictions from individual trees.

Drawing N out of N observations with replacement omits on average 37% ($1/e$) of observations for each decision tree. These are "out-of-bag"

RegressionBaggedEnsemble.oobLoss

observations. For each observation, `oobLoss` estimates the out-of-bag prediction by averaging over predictions from all trees in the ensemble for which this observation is out of bag. It then compares the computed prediction against the true response for this observation. It calculates the out-of-bag error by comparing the out-of-bag predicted responses against the true responses for all observations used for training. This out-of-bag average is an unbiased estimator of the true ensemble error.

Examples

Compute the out-of-bag error for the `carsmall` data:

```
load carsmall
X = [Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'bag',100,'Tree',...
    'type','regression');
L = oobLoss(ens)

L =
    17.0665
```

See Also

`oobPredict` | `loss`

ClassificationBaggedEnsemble.oobMargin

Purpose	Out-of-bag classification margins
Syntax	<code>margin = oobMargin(ens)</code> <code>margin = oobMargin(ens,Name,Value)</code>
Description	<code>margin = oobMargin(ens)</code> returns out-of-bag classification margins. <code>margin = oobMargin(ens,Name,Value)</code> calculates margins with additional options specified by one or more <code>Name,Value</code> pair arguments.
Input Arguments	ens A classification bagged ensemble, constructed with <code>fitensemble</code> . Name-Value Pair Arguments Specify optional comma-separated pairs of <code>Name,Value</code> arguments, where <code>Name</code> is the argument name and <code>Value</code> is the corresponding value. <code>Name</code> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <code>Name1,Value1,...,NameN,ValueN</code> . learners Indices of weak learners in the ensemble ranging from 1 to <code>ens.NTrained</code> . <code>oobEdge</code> uses only these learners for calculating loss. Default: <code>1:NTrained</code>
Output Arguments	margin A numeric column vector of length <code>size(ens.X,1)</code> .
Definitions	Out of Bag <i>Bagging</i> , which stands for “bootstrap aggregation”, is a type of ensemble learning. To bag a weak learner such as a decision tree on a dataset, <code>fitensemble</code> generates many bootstrap replicas of the dataset and

ClassificationBaggedEnsemble.oobMargin

grows decision trees on these replicas. `fitensemble` obtains each bootstrap replica by randomly selecting N observations out of N with replacement, where N is the dataset size. To find the predicted response of a trained ensemble, `predict` take an average over predictions from individual trees.

Drawing N out of N observations with replacement omits on average 37% ($1/e$) of observations for each decision tree. These are "out-of-bag" observations. For each observation, `oobLoss` estimates the out-of-bag prediction by averaging over predictions from all trees in the ensemble for which this observation is out of bag. It then compares the computed prediction against the true response for this observation. It calculates the out-of-bag error by comparing the out-of-bag predicted responses against the true responses for all observations used for training. This out-of-bag average is an unbiased estimator of the true ensemble error.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `ens.X`.

Examples

Find the out-of-bag margin for a bagged ensemble from the Fisher iris data: Find how many elements of margin are equal to 1.

```
load fisheriris
ens = fitensemble(meas,species,'Bag',100,...
    'Tree','type','classification');
margin = oobMargin(ens);
sum(margin == 1)

ans =
    108
```

See Also

`oobPredict` | `oobLoss` | `oobEdge` | `margin`

Purpose

Out-of-bag margins

Syntax

```
mar = oobMargin(B)
mar = oobMargin(B, 'param1', val1, 'param2', val2, ...)
```

Description

`mar = oobMargin(B)` computes an `Nobs`-by-`NTrees` matrix of classification margins for out-of-bag observations in the training data, using the trained bagger `B`.

`mar = oobMargin(B, 'param1', val1, 'param2', val2, ...)` specifies optional parameter name/value pairs:

'mode'	String indicating how <code>oobMargin</code> computes errors. If set to 'cumulative' (default), the method computes cumulative margins and <code>mar</code> is an <code>Nobs</code> -by- <code>NTrees</code> matrix, where the first column gives margins from <code>trees(1)</code> , second column gives margins from <code>trees(1:2)</code> etc, up to <code>trees(1:NTrees)</code> . If set to 'individual', <code>mar</code> is an <code>Nobs</code> -by- <code>NTrees</code> matrix, where each column gives margins from each tree in the ensemble. If set to 'ensemble', <code>mar</code> is a single column of length <code>Nobs</code> showing the cumulative margins for the entire ensemble.
'trees'	Vector of indices indicating what trees to include in this calculation. By default, this argument is set to 'all' and the method uses all trees. If 'trees' is a numeric vector, the method returns an <code>Nobs</code> -by- <code>NTrees</code> matrix for 'cumulative' and 'individual' modes, where <code>NTrees</code> is the number of elements in the input vector, and a single column for 'ensemble' mode. For example, in the 'cumulative' mode, the first column gives

TreeBagger.oobMargin

margins from `trees(1)`, the second column gives margins from `trees(1:2)` etc.

'treeweights' Vector of tree weights. This vector must have the same length as the 'trees' vector. `oobMargin` uses these weights to combine output from the specified trees by taking a weighted average instead of the simple nonweighted majority vote. You cannot use this argument in the 'individual' mode.

See Also

`CompactTreeBagger.margin`

Purpose

Out-of-bag mean margins

Syntax

```
mar = oobMeanMargin(B)
mar = oobMeanMargin(B, 'param1', val1, 'param2', val2, ...)
```

Description

`mar = oobMeanMargin(B)` computes average classification margins for out-of-bag observations in the training data, using the trained bagger `B`. `oobMeanMargin` averages the margins over all out-of-bag observations. `mar` is a row-vector of length `NTrees`, where `NTrees` is the number of trees in the ensemble.

`mar = oobMeanMargin(B, 'param1', val1, 'param2', val2, ...)` specifies optional parameter name/value pairs:

- 'mode' String indicating how `oobMargin` computes errors. If set to 'cumulative' (default), is a vector of length `NTrees` where the first element gives mean margin from `trees(1)`, second column gives mean margins from `trees(1:2)` etc, up to `trees(1:NTrees)`. If set to 'individual', `mar` is a vector of length `NTrees`, where each element is a mean margin from each tree in the ensemble. If set to 'ensemble', `mar` is a scalar showing the cumulative mean margin for the entire ensemble.
- 'trees' Vector of indices indicating what trees to include in this calculation. By default, this argument is set to 'all' and the method uses all trees. If 'trees' is a numeric vector, the method returns a vector of length `NTrees` for 'cumulative' and 'individual' modes, where `NTrees` is the number of elements in the input vector, and a scalar for 'ensemble' mode. For example, in the 'cumulative' mode, the first element gives mean margin from `trees(1)`, the second element gives mean margin from `trees(1:2)` etc.
- 'treeweights' Vector of tree weights. This vector must have the same length as the 'trees' vector. `oobMeanMargin` uses these weights to combine output from the specified trees by taking a weighted average instead of the simple nonweighted majority vote. You cannot use this argument in the 'individual' mode.

TreeBagger.oobMeanMargin

See Also

`CompactTreeBagger.meanMargin`

TreeBagger.OOBPermutedVarCountRaiseMargin property

Purpose Variable importance for raising margin

Description The OOBPermutedVarCountRaiseMargin property is a numeric array of size 1-by-Nvars containing a measure of variable importance for each predictor. For any variable, the measure is the difference between the number of raised margins and the number of lowered margins if the values of that variable are permuted across the out-of-bag observations. This measure is computed for every tree, then averaged over the entire ensemble and divided by the standard deviation over the entire ensemble. This property is empty for regression trees.

TreeBagger.OOBPermutedVarDeltaError property

Purpose Variable importance for prediction error

Description The `OOBPermutedVarDeltaError` property is a numeric array of size 1-by-*Nvars* containing a measure of importance for each predictor variable (feature). For any variable, the measure is the increase in prediction error if the values of that variable are permuted across the out-of-bag observations. This measure is computed for every tree, then averaged over the entire ensemble and divided by the standard deviation over the entire ensemble.

TreeBagger.OOBPermutedVarDeltaMeanMargin property

Purpose Variable importance for classification margin

Description The `OOBPermutedVarDeltaMeanMargin` property is a numeric array of size 1-by-Nvars containing a measure of importance for each predictor variable (feature). For any variable, the measure is the decrease in the classification margin if the values of that variable are permuted across the out-of-bag observations. This measure is computed for every tree, then averaged over the entire ensemble and divided by the standard deviation over the entire ensemble. This property is empty for regression trees.

ClassificationBaggedEnsemble.oobPredict

Purpose	Predict out-of-bag response of ensemble
Syntax	<pre>[label,score] = oobPredict(ens) [label,score] = oobPredict(ens,Name,Value)</pre>
Description	<p>[label,score] = oobPredict(ens) returns class labels and scores for ens for out-of-bag data.</p> <p>[label,score] = oobPredict(ens,Name,Value) computes labels and scores with additional options specified by one or more Name,Value pair arguments.</p>
Input Arguments	<p>ens</p> <p>A classification bagged ensemble, constructed with fitensemble.</p> <p>Name-Value Pair Arguments</p> <p>Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1,...,NameN,ValueN.</p> <p>learners</p> <p>Indices of weak learners in the ensemble ranging from 1 to ens.NTrained. oobEdge uses only these learners for calculating loss.</p> <p>Default: 1:NTrained</p>
Output Arguments	<p>label</p> <p>Classification labels of the same data type as the training data Y. There are N elements or rows, where N is the number of training observations. The label is the class with the highest score. In case of a tie, the label is earliest in ens.ClassNames.</p> <p>score</p>

An N-by-K numeric matrix for N observations and K classes. A high score indicates that an observation is likely to come from this class. Scores are in the range 0 to 1.

Definitions

Out of Bag

Bagging, which stands for “bootstrap aggregation”, is a type of ensemble learning. To bag a weak learner such as a decision tree on a dataset, `fitensemble` generates many bootstrap replicas of the dataset and grows decision trees on these replicas. `fitensemble` obtains each bootstrap replica by randomly selecting N observations out of N with replacement, where N is the dataset size. To find the predicted response of a trained ensemble, `predict` take an average over predictions from individual trees.

Drawing N out of N observations with replacement omits on average 37% ($1/e$) of observations for each decision tree. These are "out-of-bag" observations. For each observation, `oobLoss` estimates the out-of-bag prediction by averaging over predictions from all trees in the ensemble for which this observation is out of bag. It then compares the computed prediction against the true response for this observation. It calculates the out-of-bag error by comparing the out-of-bag predicted responses against the true responses for all observations used for training. This out-of-bag average is an unbiased estimator of the true ensemble error.

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

ClassificationBaggedEnsemble.oobPredict

Examples

Find the out-of-bag predictions and scores for the Fisher iris data. Find the scores in the range (0.2,0.8); these are the scores where there is notable uncertainty in the resulting classifications.

```
load fisheriris
ens = fitensemble(meas,species,'Bag',100,...
    'Tree','type','classification');
[label score] = oobPredict(ens);
unsure = ( (score > .2) & (score < .8));
sum(sum(unsure)) % How many uncertain predictions?

ans =
    16
```

See Also

[oobMargin](#) | [oobPredict](#) | [oobLoss](#) | [oobEdge](#) | [predict](#)

Purpose Predict out-of-bag response of ensemble

Syntax
`Yfit = oobPredict(ens)`
`Yfit = oobPredict(ens,Name,Value)`

Description `Yfit = oobPredict(ens)` returns the predicted responses for the out-of-bag data in `ens`.

`Yfit = oobPredict(ens,Name,Value)` predicts responses with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments
ens
A regression bagged ensemble, constructed with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

Indices of weak learners in the ensemble ranging from 1 to `NTrained`. `oobLoss` uses only these learners for calculating loss.

Default: `1:NTrained`

Output Arguments
Yfit
A vector of predicted responses for out-of-bag data. `Yfit` has `size(ens.X,1)` elements.

You can find the indices of out-of-bag observations for weak learner `L` with the command

`~ens.UseObsForLearner(:,L)`

RegressionBaggedEnsemble.oobPredict

Definitions

Out of Bag

Bagging, which stands for “bootstrap aggregation”, is a type of ensemble learning. To bag a weak learner such as a decision tree on a dataset, `fitensemble` generates many bootstrap replicas of the dataset and grows decision trees on these replicas. `fitensemble` obtains each bootstrap replica by randomly selecting N observations out of N with replacement, where N is the dataset size. To find the predicted response of a trained ensemble, `predict` take an average over predictions from individual trees.

Drawing N out of N observations with replacement omits on average 37% ($1/e$) of observations for each decision tree. These are "out-of-bag" observations. For each observation, `oobLoss` estimates the out-of-bag prediction by averaging over predictions from all trees in the ensemble for which this observation is out of bag. It then compares the computed prediction against the true response for this observation. It calculates the out-of-bag error by comparing the out-of-bag predicted responses against the true responses for all observations used for training. This out-of-bag average is an unbiased estimator of the true ensemble error.

Examples

Compute out-of-bag predictions for the `carsmall` data. Look at the first three terms of the fit:

```
load carsmall
X = [Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'bag',100,'Tree',...
    'type','regression');
Yfit = oobPredict(ens);
Yfit(1:3) % first three terms

ans =
    15.7964
    14.7162
    14.8062
```

See Also

`oobLoss` | `predict`

Purpose Ensemble predictions for out-of-bag observations

Syntax `Y = oobPredict(B)`
`Y = oobPredict(B, 'param1', val1, 'param2', val2, ...)`

Description `Y = oobPredict(B)` computes predicted responses using the trained bagger `B` for out-of-bag observations in the training data. The output has one prediction for each observation in the training data. The returned `Y` is a cell array of strings for classification and a numeric array for regression.

`Y = oobPredict(B, 'param1', val1, 'param2', val2, ...)` specifies optional parameter name/value pairs:

`'trees'` Array of tree indices to use for computation of responses. Default is `'all'`.

`'treeweights'` Array of `N`Tree weights for weighting votes from the specified trees.

See Also `CompactTreeBagger.predict` | `OoBIndices`

ordinal

Superclasses categorical

Purpose Arrays for ordinal categorical data

Description Ordinal arrays are used to store discrete values that have an ordering but are not numeric. An ordinal array provides efficient storage and convenient manipulation of such data, while also maintaining meaningful labels for the values. Ordinal arrays are often used as grouping variables.

Like a numerical array, an ordinal array can have any size or dimension. You can subscript, concatenate, reshape, sort, etc. ordinal arrays, much like ordinary numeric arrays. You can make comparisons between elements of two ordinal arrays, or between an ordinal array and a single string representing a ordinal value.

Construction Use the `ordinal` constructor to create an ordinal array from a numeric, logical, or character array, or from a cell array of strings.

<code>ordinal</code>	Construct ordinal categorical array
----------------------	-------------------------------------

Methods Each ordinal array carries along a list of possible values that it can store, known as its levels. The list is created when you create an ordinal array, and you can access it using the `getlevels` method, or modify it using the `addlevels`, `mergelevels`, or `droplevels` methods. Assignment to the array will also add new levels automatically if the values assigned are not already levels of the array. The ordering on values stored in an ordinal array is defined by the order of the list of levels. You can change that order using the `reorderlevels` method.

The following table lists operations available for ordinal arrays.

<code>ismember</code>	Test for membership
<code>mergelevels</code>	Merge levels

sort	Sort elements of ordinal array
sortrows	Sort rows

Inherited Methods

Methods in the following table are inherited from `categorical`.

addlevels	Add levels to categorical array
cat	Concatenate categorical arrays
cellstr	Convert categorical array to cell array of strings
char	Convert categorical array to character array
circshift	Shift categorical array circularly
ctranspose	Transpose categorical matrix
disp	Display categorical array
display	Display categorical array
double	Convert categorical array to double array
droplevels	Drop levels
end	Last index in indexing expression for categorical array
flipdim	Flip categorical array along specified dimension
fliplr	Flip categorical matrix in left/right direction
flipud	Flip categorical matrix in up/down direction
getlabels	Access categorical array labels
getlevels	Get categorical array levels

hist	Plot histogram of categorical data
horzcat	Horizontal concatenation for categorical arrays
int16	Convert categorical array to signed 16-bit integer array
int32	Convert categorical array to signed 32-bit integer array
int64	Convert categorical array to signed 64-bit integer array
int8	Convert categorical array to signed 8-bit integer array
intersect	Set intersection for categorical arrays
ipermute	Inverse permute dimensions of categorical array
isempty	True for empty categorical array
isequal	True if categorical arrays are equal
islevel	Test for levels
ismember	True for elements of categorical array in set
isscalar	True if categorical array is scalar
isundefined	Test for undefined elements
isvector	True if categorical array is vector
length	Length of categorical array
levelcounts	Element counts by level
ndims	Number of dimensions of categorical array

numel	Number of elements in categorical array
permute	Permute dimensions of categorical array
reorderlevels	Reorder levels
repmat	Replicate and tile categorical array
reshape	Resize categorical array
rot90	Rotate categorical matrix 90 degrees
setdiff	Set difference for categorical arrays
setlabels	Label levels
setxor	Set exclusive-or for categorical arrays
shiftdim	Shift dimensions of categorical array
single	Convert categorical array to single array
size	Size of categorical array
squeeze	Squeeze singleton dimensions from categorical array
subsasgn	Subscripted assignment for categorical array
subsindex	Subscript index for categorical array
subsref	Subscripted reference for categorical array

ordinal

summary	Summary statistics for categorical array
times	Product of categorical arrays
transpose	Transpose categorical matrix
uint16	Convert categorical array to unsigned 16-bit integers
uint32	Convert categorical array to unsigned 32-bit integers
uint64	Convert categorical array to unsigned 64-bit integers
uint8	Convert categorical array to unsigned 8-bit integers
union	Set union for categorical arrays
unique	Unique values in categorical array
vertcat	Vertical concatenation for categorical arrays

Properties

Inherited Properties

Properties in the following table are inherited from `categorical`.

labels	Text labels for levels
undeflabel	Text label for undefined levels

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

Examples

Create an ordinal array from integer data:

```
quality = ordinal([1 2 3; 3 2 1; 2 1 3],{'low' 'medium' 'high'})
```



```
% Find elements meeting a criterion
quality >= 'medium'
ismember(quality,{'low' 'high'})

% Compare two ordinal arrays
quality2 = flip1r(quality)
quality == quality2
```

References

[1] Johnson, N. L., S. Kotz, and A. W. Kemp, *Univariate Discrete Distributions*, 2nd edition, Wiley, 1992, pp. 124-130.

See Also

histc | nominal

ordinal

Purpose Construct ordinal categorical array

Syntax

```
B = ordinal(A)
B = ordinal(A,labels)
B = ordinal(A,labels,levels)
B = ordinal(A,labels,[],edges)
```

Description

`B = ordinal(A)` creates an ordinal array `B` from the array `A`. `A` can be numeric, logical, character, categorical, or a cell array of strings. `ordinal` creates the levels of `B` from the sorted unique values in `A`, and creates default labels for them.

`B = ordinal(A,labels)` labels the levels in `B` using the character array or cell array of strings `labels`. `ordinal` assigns labels to levels in `B` in order according to the sorted unique values in `A`.

`B = ordinal(A,labels,levels)` creates an ordinal array with possible levels defined by `levels`. `levels` is a vector whose values can be compared to those in `A` using the equality operator. `ordinal` assigns labels to each level from the corresponding elements of `labels`. If `A` contains any values not present in `levels`, the levels of the corresponding elements of `B` are undefined. Use `[]` for `labels` to allow `ordinal` to create default labels.

`B = ordinal(A,labels,[],edges)` creates an ordinal array by binning the numeric array `A`, with bin edges given by the numeric vector `edges`. The uppermost bin includes values equal to the right-most edge. `ordinal` assigns labels to each level in `B` from the corresponding elements of `labels`. `edges` must have one more element than `labels`.

By default, an element of `B` is undefined if the corresponding element of `A` is `NaN` (when `A` is numeric), an empty string (when `A` is character), or undefined (when `A` is categorical). `ordinal` treats such elements as “undefined” or “missing” and does not include entries for them among the possible levels for `B`. To create an explicit level for such elements instead of treating them as undefined, you must use the `levels` input, and include `NaN`, the empty string, or an undefined element.

You may include duplicate labels in `labels` in order to merge multiple values in A into a single level in B.

Examples

Create an ordinal array from integer data, and provide explicit labels:

```
quality1 = ordinal([1 2 3; 3 2 1; 2 1 3],...
    {'low' 'medium' 'high'})
```

Create an ordinal array from integer data, and provide both explicit labels and an explicit order:

```
quality2 = ordinal([1 2 3; 3 2 1; 2 1 3],...
    {'high' 'medium' 'low'},[3 2 1])
```

Create an ordinal array by binning floating point values:

```
size = ordinal(rand(5,2),{'small' 'medium' 'large'},...
    [],[0 1/3 2/3 1])
```

Create an ordinal array from the measurements in Fisher's iris data, ignoring decimal lengths:

```
load fisheriris
m = floor(min(meas(:)));
M = floor(max(meas(:)));
labels = num2str((m:M)');
edges = m:M+1;
cms = ordinal(meas,labels,[],edges)

meas(1:5,:)
ans =
    5.1000    3.5000    1.4000    0.2000
    4.9000    3.0000    1.4000    0.2000
```

ordinal

```
      4.7000    3.2000    1.3000    0.2000
      4.6000    3.1000    1.5000    0.2000
      5.0000    3.6000    1.4000    0.2000
cms(1:5,:)
ans =
     5     3     1     0
     4     3     1     0
     4     3     1     0
     4     3     1     0
     5     3     1     0
```

Create an age group ordinal array from the data in `hospital.mat`:

```
load hospital
edges = 0:10:100;
labels = strcat(num2str((0:10:90)', '%d'), {'s'});
AgeGroup = ordinal(hospital.Age, labels, [], edges);
```

```
hospital.Age(1:5)
ans =
    38
    43
    38
    40
    49
```

```
AgeGroup(1:5)
ans =
    30s
    40s
    30s
    40s
    40s
```

See Also

[histc](#) | [nominal](#)

Purpose

Outlier measure for data

Syntax

```
out = outlierMeasure(B,X)
out = outlierMeasure(B,X,'param1',val1,'param2',val2,...)
```

Description

`out = outlierMeasure(B,X)` computes outlier measures for predictors `X` using trees in the ensemble `B`. The method computes the outlier measure for a given observation by taking an inverse of the average squared proximity between this observation and other observations. `outlierMeasure` then normalizes these outlier measures by subtracting the median of their distribution, taking the absolute value of this difference, and dividing by the median absolute deviation. A high value of the outlier measure indicates that this observation is an outlier.

You can supply the proximity matrix directly by using the `'data'` parameter.

`out = outlierMeasure(B,X,'param1',val1,'param2',val2,...)` specifies optional parameter name/value pairs:

<code>'data'</code>	Flag indicating how to treat the <code>X</code> input argument. If set to <code>'predictors'</code> (default), the method assumes <code>X</code> is a matrix of predictors and uses it for computation of the proximity matrix. If set to <code>'proximity'</code> , the method treats <code>X</code> as a proximity matrix returned by the <code>proximity</code> method. If you do not supply the proximity matrix, <code>outlierMeasure</code> computes it internally. If you use the <code>proximity</code> method to compute a proximity matrix, supplying it as input to <code>outlierMeasure</code> reduces computing time.
<code>'labels'</code>	Vector of true class labels. True class labels can be either a numeric vector, character matrix, or cell array of strings. When you supply this parameter, the method performs the outlier calculation for any observations using only other observations from the same class. This parameter must specify one label for each observation (row) in <code>X</code> .

CompactTreeBagger.outlierMeasure

See Also

`proximity`

TreeBagger.OutlierMeasure property

Purpose Measure for determining outliers

Description The OutlierMeasure property is a numeric array of size Nobs-by-1, where Nobs is the number of observations in the training data, containing outlier measures for each observation.

See Also CompactTreeBagger.outlierMeasure

parallelcoords

Purpose Parallel coordinates plot

Syntax

```
parallelcoords(X)
parallelcoords(X,...,'Standardize','on')
parallelcoords(X,...,'Standardize','PCA')
parallelcoords(X,...,'Standardize','PCAStd')
parallelcoords(X,...,'Quantile',alpha)
parallelcoords(X,...,'Group',group)
parallelcoords(X,...,'Labels',labels)
parallelcoords(X,...,PropertyName,PropertyValue,...)
h = parallelcoords(X,...)
parallelcoords(axes,...)
```

Description `parallelcoords(X)` creates a parallel coordinates plot of the multivariate data in the n -by- p matrix X . Rows of X correspond to observations, columns to variables. A parallel coordinates plot is a tool for visualizing high dimensional data, where each observation is represented by the sequence of its coordinate values plotted against their coordinate indices. `parallelcoords` treats NaNs in X as missing values and does not plot those coordinate values.

`parallelcoords(X,...,'Standardize','on')` scales each column of X to have mean 0 and standard deviation 1 before making the plot.

`parallelcoords(X,...,'Standardize','PCA')` creates a parallel coordinates plot from the principal component scores of X , in order of decreasing eigenvalues. `parallelcoords` removes rows of X containing missing values (NaNs) for principal components analysis (PCA) standardization.

`parallelcoords(X,...,'Standardize','PCAStd')` creates a parallel coordinates plot using the standardized principal component scores.

`parallelcoords(X,...,'Quantile',alpha)` plots only the median and the α and $1-\alpha$ quantiles of $f(t)$ at each value of t . This is useful if X contains many observations.

`parallelcoords(X,...,'Group',group)` plots the data in different groups with different colors. Groups are defined by `group`, a numeric

array containing a group index for each observation. `group` can also be a categorical variable, character matrix, or cell array of strings, containing a group name for each observation.

`parallelcoords(X,...,'Labels',labels)` labels the coordinate tick marks along the horizontal axis using `labels`, a character array or cell array of strings.

`parallelcoords(X,...,PropertyName,PropertyValue,...)` sets properties to the specified property values for all line graphics objects created by `parallelcoords`.

`h = parallelcoords(X,...)` returns a column vector of handles to the line objects created by `parallelcoords`, one handle per row of `X`. If you use the `'Quantile'` input argument, `h` contains one handle for each of the three lines objects created. If you use both the `'Quantile'` and the `'Group'` input arguments, `h` contains three handles for each group.

`parallelcoords(axes,...)` plots into the axes with handle axes.

Examples

```
% Make a grouped plot of the raw data
load fisheriris
labels = {'Sepal Length','Sepal Width',...
         'Petal Length','Petal Width'};
parallelcoords(meas,'group',species,'labels',labels);
```

```
% Plot only the median and quartiles of each group
parallelcoords(meas,'group',species,'labels',labels,...
              'quantile',.25);
```

See Also

`andrewsplot` | `glyphplot`

How To

- “Grouping Variables” on page 2-72

ProbDistUnivParam.paramci

Purpose Return parameter confidence intervals of ProbDistUnivParam object

Syntax CI = paramci(PD)
CI = paramci(PD, Alpha)

Description CI = paramci(PD) returns CI, a 2-by-N array containing 95% confidence intervals for the parameters of the ProbDistUnivParam object PD. N is the number of parameters in the distribution. When you create PD by specifying parameters (such as using the ProbDistUnivParam.ProbDistUnivParam constructor or using the fitdist function and specifying a 'binomial' or 'generalized pareto' distribution) rather than by fitting to data, the confidence intervals have a width of 0 because the parameters are viewed as estimates of an unknown parameter.

CI = paramci(PD, Alpha) returns 100*(1 - Alpha)% confidence intervals. Default Alpha is 0.05, which specifies 95% confidence intervals.

Note If you create PD with a distribution that does not support confidence intervals, then CI contains NaN values.

Input Arguments

PD	An object of the class ProbDistUnivParam.
Alpha	A value between 0 and 1 that specifies a confidence interval. Default is 0.05, which specifies 95% confidence intervals.

Output Arguments

CI	A 2-by-N array containing 100*(1 - Alpha)% confidence intervals for the parameters of the ProbDistUnivParam object PD. N is the number of parameters in the distribution.
----	---

See Also `fitdist`

ProbDistParametric.ParamCov property

Purpose	Read-only covariance matrix of parameter estimates of ProbDistParametric object
Description	ParamCov is a read-only property of the ProbDistParametric class. ParamCov is a covariance matrix containing the parameter estimates of a distribution represented by a ProbDistParametric object. ParamCov has a size of NumParams-by-NumParams.
Values	This covariance matrix includes estimates for both the specified parameters and parameters that are fit to the data. For specified parameters, the covariance is 0, indicating the parameter is known exactly. Use this information to view and compare the descriptions of parameters supplied to create distributions.

ProbDistParametric.ParamDescription property

Purpose	Read-only cell array specifying descriptions of parameters of ProbDistParametric object
Description	ParamDescription is a read-only property of the ProbDistParametric class. ParamDescription is a cell array of strings specifying the descriptions or meanings of the parameters of a distribution represented by a ProbDistParametric object. ParamDescription has a length of NumParams.
Values	This cell array includes a brief description of the meaning of both the specified parameters and parameters that are fit to the data. The description is the same as the parameter name when no further description information is available. Use this information to view and compare the descriptions of parameters used to create distributions.

ProbDistParametric.ParamIsFixed property

Purpose	Read-only logical array specifying fixed parameters of ProbDistParametric object
Description	ParamIsFixed is a read-only property of the ProbDistParametric class. ParamIsFixed is a logical array specifying the fixed parameters of a distribution represented by a ProbDistParametric object. ParamIsFixed has a length of NumParams.
Values	This array specifies a 1 (true) for fixed parameters, and a 0 (false) for parameters that are estimated from the input data. Use this information to view and compare the fixed parameters used to create distributions.

ProbDistParametric.ParamNames property

Purpose

Read-only cell array specifying names of parameters of ProbDistParametric object

Description

ParamNames is a read-only property of the ProbDistParametric class. ParamNames is a cell array of strings specifying the names of the parameters of a distribution represented by a ProbDistParametric object. ParamNames has a length of NumParams.

Values

This cell array includes the names of both the specified parameters and parameters that are fit to the data. Use this information to view and compare the names of parameters used to create distributions.

NaiveBayes.Params property

Purpose Parameter estimates

Description The Params property is an NClasses-by-NDims cell array containing the parameter estimates, excluding the class priors. Params(i, j) contains the parameter estimates for the jth feature in the ith class. Params(i, j) is an empty cell if the ith class is empty.

The entry in Params(i, j) depends on the distribution type used for the jth feature, as follows:

'normal'	A vector of length two. The first element is the mean, and the second element is standard deviation.
'kernel'	A ProbDistUnivKernel object
'mvmn'	A vector containing the probability for each possible value of the jth feature in the ith class. The order of the probabilities is decided by the sorted order of all the unique values of the jth feature.
'mn'	A scalar representing the probability the jth token appearing in the ith class, Prob(token j class i). It is estimated as $(1 + \text{the number of occurrence of token J in class I}) / (\text{NDims} + \text{the total number of token occurrence in class I})$.

ProbDistParametric.Params property

Purpose	Read-only array specifying values of parameters of ProbDistParametric object
Description	Params is a read-only property of the ProbDistParametric class. Params is an array of values specifying the values of the parameters of a distribution represented by a ProbDistParametric object. Params has a length of NumParams.
Values	This array includes the values of both the specified parameters and parameters that are fit to the data. Use this information to view and compare the values of parameters used to create distributions.

classregtree.parent

Purpose

Parent node

Syntax

```
p = parent(t)
p = parent(t,nodes)
```

Description

`p = parent(t)` returns an n -element vector `p` containing the number of the parent node for each node in the tree `t`, where n is the number of nodes. The parent of the root node is 0.

`p = parent(t,nodes)` takes a vector `nodes` of node numbers and returns the parent nodes for the specified nodes.

Examples

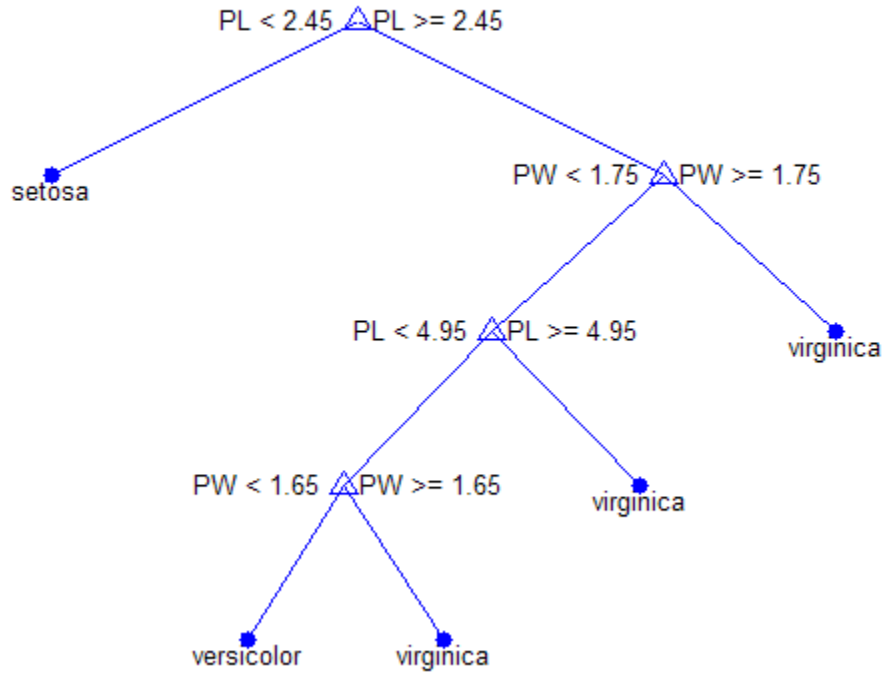
Create a classification tree for Fisher's iris data:

```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 else node 3
2  class = setosa
3  if PW<1.75 then node 4 else node 5
4  if PL<4.95 then node 6 else node 7
5  class = virginica
6  if PW<1.65 then node 8 else node 9
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

Click to display: Magnification: Pruning level:



p = parent(t)

p =

0

1

1

3

3

4

4

6

classregtree.parent

6

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

`classregtree` | `children` | `numnodes`

Superclasses	piecewisedistribution	
Purpose	Empirical distributions with Pareto tails	
Construction	paretotails	Construct Pareto tails object
Methods	lowerparams	Lower Pareto tails parameters
	upperparams	Upper Pareto tails parameters

Inherited Methods

Methods in the following table are inherited from piecewisedistribution.

boundary	Piecewise distribution boundaries
cdf	Cumulative distribution function for piecewise distribution
disp	Display piecewisedistribution object
display	Display piecewisedistribution object
icdf	Inverse cumulative distribution function for piecewise distribution
nsegments	Number of segments
pdf	Probability density function for piecewise distribution
random	Random numbers from piecewise distribution
segment	Segments containing values

paretotails

Properties

Objects of the `paretotails` class have no properties accessible by dot indexing, `get` methods, or `set` methods. To obtain information about a `paretotails` object, use the appropriate method.

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

How To

- “Generalized Pareto Distribution” on page B-50

Purpose Construct Pareto tails object

Syntax
`obj = paretotails(x,p1,pu)`
`obj = paretotails(x,p1,pu,cdffun)`

Description `obj = paretotails(x,p1,pu)` creates an object `obj` defining a distribution consisting of the empirical distribution of `x` in the center and Pareto distributions in the tails. `x` is a real-valued vector of data values whose extreme observations are fit to generalized Pareto distributions (GPDs). `p1` and `pu` identify the lower- and upper-tail cumulative probabilities such that $100 \cdot p1$ and $100 \cdot (1 - pu)$ percent of the observations in `x` are, respectively, fit to a GPD by maximum likelihood. If `p1` is 0, or if there are not at least two distinct observations in the lower tail, then no lower Pareto tail is fit. If `pu` is 1, or if there are not at least two distinct observations in the upper tail, then no upper Pareto tail is fit.

`obj = paretotails(x,p1,pu,cdffun)` uses `cdffun` to estimate the cdf of `x` between the lower and upper tail probabilities. `cdffun` may be any of the following:

- 'ecdf' — Uses an interpolated empirical cdf, with data values as the midpoints in the vertical steps in the empirical cdf, and computed by linear interpolation between data values. This is the default.
- 'kernel' — Uses a kernel-smoothing estimate of the cdf.
- @fun — Uses a handle to a function of the form `[p,xi] = fun(x)` that accepts the input data vector `x` and returns a vector `p` of cdf values and a vector `xi` of evaluation points. Values in `xi` must be sorted and distinct but need not equal the values in `x`.

`cdffun` is used to compute the quantiles corresponding to `p1` and `pu` by inverse interpolation, and to define the fitted distribution between these quantiles.

The output object `obj` is a Pareto tails object with methods to evaluate the cdf, inverse cdf, and other functions of the fitted distribution. These methods are well-suited to copula and other Monte Carlo simulations.

paretotails

The pdf method in the tails is the GPD density, but in the center it is computed as the slope of the interpolated cdf.

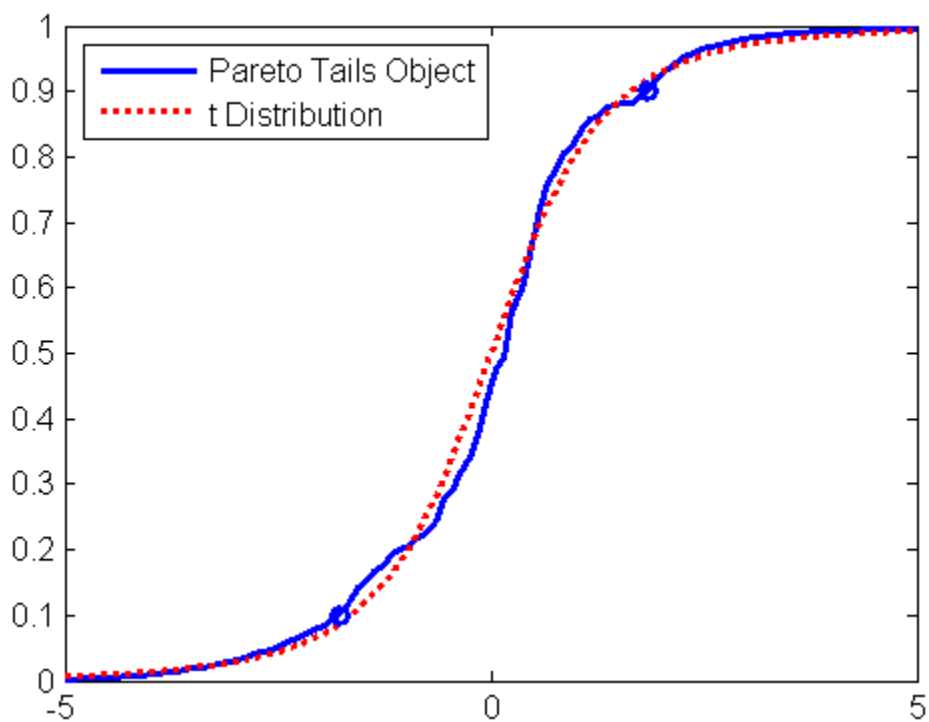
The `paretotails` class is a subclass of the `piecewisedistribution` class, and many of its methods are derived from that class.

Examples

Fit Pareto tails to a t distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);
obj = paretotails(t,0.1,0.9);
[p,q] = boundary(obj);

x = linspace(-5,5);
plot(x,cdf(obj,x),'b-','LineWidth',2)
hold on
plot(x,tcdf(x,3),'r:','LineWidth',2)
plot(q,p,'bo','LineWidth',2,'MarkerSize',5)
legend('Pareto Tails Object','t Distribution',...
       'Location','NW')
```


**See Also**

[cdf](#) | [ecdf](#) | [gpfitt](#) | [icdf](#) | [ksdensity](#)

partialcorr

Purpose Linear or rank partial correlation coefficients

Syntax

```
RHO = partialcorr(X)
RHO = partialcorr(X,Z)
RHO = partialcorr(X,Y,Z)
[RHO,PVAL] = partialcorr(...)
[...] = partialcorr(...,param1,val1,param2,val2,...)
```

Description `RHO = partialcorr(X)` returns the sample linear partial correlation coefficients between pairs of variables in X , controlling for the remaining variables in X . X is an n -by- p matrix, with rows corresponding to observations, and columns corresponding to variables. RHO is a symmetric p -by- p matrix, where the (i,j) -th entry is the sample linear partial correlation between the i -th and j -th columns in X .

`RHO = partialcorr(X,Z)` returns the sample linear partial correlation coefficients between pairs of variables in X controlling for the variables in Z . X is an n -by- p matrix, and Z is an n -by- q matrix with rows corresponding to observations, and columns corresponding to variables. The output, RHO , is a symmetric p -by- p matrix.

`RHO = partialcorr(X,Y,Z)` returns the sample linear partial correlation coefficients between pairs of variables between X and Y , controlling for the variables in Z . X is an n -by- p_1 matrix, Y an n -by- p_2 matrix, and Z is an n -by- q matrix, with rows corresponding to observations, and columns corresponding to variables. RHO is a p_1 -by- p_2 matrix, where the (i,j) th entry is the sample linear partial correlation between the i th column in X and the j th column in Y .

If the covariance matrix of $[X,Z]$ is

$$S = \begin{pmatrix} S_{11} & S_{12} \\ S_{12}^T & S_{22} \end{pmatrix}$$

then the partial correlation matrix of X , controlling for Z , can be defined formally as a normalized version of the covariance matrix $S_{xy} = S_{11} - (S_{12}S_{22}^{-1}S_{12}^T)$

[RHO,PVAL] = partialcorr(...) also returns PVAL, a matrix of p -values for testing the hypothesis of no partial correlation against the alternative that there is a nonzero partial correlation. Each element of PVAL is the p value for the corresponding element of RHO. If PVAL(I,J) is small, say less than 0.05, then the partial correlation, RHO(I,J), is significantly different from zero.

[...] = partialcorr(...,param1,val1,param2,val2,...) specifies additional parameters and their values. Valid parameter/value pairs are listed in the following table.

Parameter	Values
'type'	<ul style="list-style-type: none"> 'Pearson' — To compute Pearson (linear) partial correlations. This is the default. 'Spearman' — To compute Spearman (rank) partial correlations.
'rows'	<ul style="list-style-type: none"> 'all' — To use all rows regardless of missing (NaN) values. This is the default. 'complete' — To use only rows with no missing values. 'pairwise' — To compute RHO(I,J) using rows with no missing values in column I or J.
'tail' The alternative hypothesis against which to compute p -values for testing the hypothesis of no partial correlation.	<ul style="list-style-type: none"> 'both' (the default) — the correlation is not zero. 'right' — the correlation is greater than zero. 'left' — the correlation is less than zero.

partialcorr

A 'pairwise' value for the rows parameter can produce a RHO that is not positive definite. A 'complete' value always produces a positive definite RHO, but when data is missing, the estimates will be based on fewer observations, in general.

partialcorr computes p -values for linear and rank partial correlations using a Student's t distribution for a transformation of the correlation. This is exact for linear partial correlation when X and Z are normal, but is a large-sample approximation otherwise.

See Also

corr | tiedrank | corrccoef

Purpose

Principal component analysis of raw data

Syntax

```
coeff = pca(X)
[coeff,score] = pca(X)
[coeff,score,latent] = pca(X)
[coeff,score,latent,tsquared] = pca(X)
[coeff,score,latent,tsquared,explained] = pca(X)
[ ___ ] = pca(X,Name,Value)
```

Description

`coeff = pca(X)` returns the principal component coefficients for the n -by- p data matrix X . Rows of X correspond to observations and columns to variables. The coefficient matrix is p -by- p . Each column of `coeff` contains coefficients for one principal component, and the columns are in descending order of component variance.

By default, `pca` centers the data and uses the singular value decomposition (SVD) algorithm. For the other options, use the `Name,Value` pair arguments.

`[coeff,score] = pca(X)` also returns the principal component scores, which are the representations of X in the principal component space. Rows of `score` correspond to observations and columns correspond to components.

`[coeff,score,latent] = pca(X)` also returns the principal component variances, which are the eigenvalues of the covariance matrix of X , in `latent`.

`[coeff,score,latent,tsquared] = pca(X)` also returns the Hotelling's T-squared statistic for each observation in X .

`[coeff,score,latent,tsquared,explained] = pca(X)` also returns the vector, `explained`, which shows the percentage of the total variance explained by each principal component.

[___] = `pca(X,Name,Value)` returns any of the output arguments in the previous syntaxes using additional options for computation and handling of special data types, specified by one or more `Name,Value` pair arguments.

Input Arguments

X - Input data

matrix

Input data for which to compute the principal components, specified as an n -by- p matrix. Rows of `X` correspond to observations and columns to variables.

Data Types

single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example:

`'Algorithm','eig','Centered',false,'Rows','all','NumComponents',3` specifies that `pca` uses eigenvalue decomposition algorithm, not center the data, use all of the observations, and return only the first three principal components.

Algorithm - Principal component algorithm

`'svd'` (default) | `'eig'`

Principal component algorithm that `pca` uses to perform the principal component analysis, specified as the comma-separated pair consisting of `'Algorithm'` and one of these expressions.

'svd'	Singular value decomposition (SVD) of X (default).
'eig'	Eigenvalue decomposition (EIG) of the covariance matrix. The EIG algorithm is faster than SVD when the number of observations, n , exceeds the number of variables, p , but is less accurate because the condition number of the covariance is the square of the condition number of X.

Example: 'Algorithm','eig'

Data Types

char

Centered - Indicator for centering columns

true (default) | false

Indicator for centering the columns, specified as the comma-separated pair consisting of 'Centered' and one of these logical expressions.

true	Default. pca centers X by subtracting column means before computing singular value decomposition or eigenvalue decomposition. If X contains NaN missing values, nanmean is used to find the mean with any available data. You can reconstruct the centered data using <code>score*coeff'</code> .
false	In this case pca does not center the data. You can reconstruct the original data using <code>score*coeff'</code> .

Example: 'Centered',false

Data Types

logical

Economy - Indicator for economy size output

true (default) | false

Indicator for the economy size output when the “Degrees of Freedom” on page 20-1674, d , is smaller than the number of variables, p , specified as the comma-separated pair consisting of 'Economy' and one of these logical expressions.

true	<p>Default. <code>pca</code> returns only the first d elements of <code>latent</code> and the corresponding columns of <code>coeff</code> and <code>score</code>.</p> <p>This option can be significantly faster when the number of variables p is much larger than d.</p>
false	<p><code>pca</code> returns all elements of <code>latent</code>. The columns of <code>coeff</code> and <code>score</code> corresponding to zero elements in <code>latent</code> are zeros.</p>

Note that when $d < p$, `score(:,d+1:p)` and `latent(d+1:p)` are necessarily zero, and the columns of `coeff(:,d+1:p)` define directions that are orthogonal to X .

Example: 'Economy',false

Data Types

logical

NumComponents - Number of components requested

number of variables (default) | scalar integer

The number of components requested, specified as the comma-separated pair consisting of 'NumComponents' and a scalar integer k satisfying $0 < k \leq p$, where p is the number of original variables in X . When specified, `pca` returns the first k columns of `coeff` and `score`.

Example: 'NumComponents',3

Data Types

single | double

Rows - Action to take for NaN values

'complete' (default) | 'pairwise' | 'all'

Action to take for NaN values in the data matrix X , specified as the comma-separated pair consisting of 'Rows' and one of the following.

'complete'	The default action. Observations with NaN values are removed before calculation. Rows of NaNs are inserted back into <code>score</code> and <code>tsquared</code> at the corresponding locations.
'pairwise'	<p>This option only applies when the algorithm is 'eig'. If you don't specify the algorithm along with 'pairwise', then <code>pca</code> sets it to 'eig'. If you specify 'svd' as the algorithm, along with the option 'Rows', 'pairwise', then <code>pca</code> returns a warning message, sets the algorithm to 'eig' and continues.</p> <p>When you specify the 'Rows', 'pairwise' option, <code>pca</code> computes the (i,j) element of the covariance matrix using the rows with no NaN values in the columns i or j of X.</p> <p>Note that, the resulting covariance matrix might not be positive definite. In that case, <code>pca</code> terminates with an error message.</p>
'all'	X is expected to have no missing values. <code>pca</code> uses all of the data and terminates if any NaN value is found.

Example: 'Rows','pairwise'

Data Types

char

Weights - Observation weights

ones (default) | row vector

Observation weights, specified as the comma-separated pair consisting of 'Weights' and a vector of length n containing all positive elements.

Data Types

single | double

VariableWeights - Variable weights

row vector | 'variance'

"Variable Weights" on page 20-1675, specified as the comma-separated pair consisting of 'VariableWeights' and one of the following.

Vector of length p containing all positive elements.

The string 'variance'. The variable weights are the inverse of sample variance. If you also assign weights to observations using 'Weights', then the variable weights become the inverse of weighted sample variance.

If 'Centered' is set true at the same time, the data matrix X is centered and standardized. In this case, `pca` returns the principal components based on the correlation matrix.

Example: 'VariableWeights','variance'

Data Types

single | double | char

Output Arguments

coeff - Principal component coefficients

matrix

Principal component coefficients, returned as a p -by- p matrix. Each column of `coeff` contains coefficients for one principal component. The columns are in the order of descending component variance, `latent`.

score - Principal component scores

matrix

Principal component scores, returned as a matrix. Rows of `score` correspond to observations, and columns to components.

latent - Principal component variances

column vector

Principal component variances, that is the eigenvalues of the covariance matrix of X , returned as a column vector.

tsquared - Hotelling's T-squared statistic

column vector

“Hotelling’s T-squared Statistic” on page 20-1674, which is the sum of squares of the standardized scores for each observation, returned as a column vector.

explained - Percentage of total variance explained

column vector

Percentage of the total variance explained by each principal component, returned as a column vector.

Examples

Principal Components of a Data Set

Load the sample data set.

```
load hald
```

The ingredients data has 13 observations for 4 variables.

Find the principal components for the ingredients data.

```
coeff = pca(ingredients)
```

```
coeff =
```

```

-0.0678   -0.6460    0.5673    0.5062
-0.6785   -0.0200   -0.5440    0.4933
 0.0290    0.7553    0.4036    0.5156
 0.7309   -0.1085   -0.4684    0.4844
```

The rows of `coeff` contain the coefficients for the four ingredient variables, and its columns correspond to four principal components.

Principal Component Coefficients, Scores, and Variances

Find the coefficients, scores, and variances of the principal components.

Load sample data set.

```
load hald
```

The ingredients data has 13 observations for 4 variables.

Find the principal component coefficients, scores, and variances of the components for the ingredients data.

```
[coeff,score,latent] = pca(ingredients)
```

```
coeff =
```

-0.0678	-0.6460	0.5673	0.5062
-0.6785	-0.0200	-0.5440	0.4933
0.0290	0.7553	0.4036	0.5156
0.7309	-0.1085	-0.4684	0.4844

```
score =
```

36.8218	-6.8709	-4.5909	0.3967
29.6073	4.6109	-2.2476	-0.3958
-12.9818	-4.2049	0.9022	-1.1261
23.7147	-6.6341	1.8547	-0.3786
-0.5532	-4.4617	-6.0874	0.1424
-10.8125	-3.6466	0.9130	-0.1350
-32.5882	8.9798	-1.6063	0.0818
22.6064	10.7259	3.2365	0.3243
-9.2626	8.9854	-0.0169	-0.5437
-3.2840	-14.1573	7.0465	0.3405
9.2200	12.3861	3.4283	0.4352
-25.5849	-2.7817	-0.3867	0.4468
-26.9032	-2.9310	-2.4455	0.4116

```
latent =
```

```
517.7969  
67.4964  
12.4054
```

0.2372

Each column of `score` corresponds to one principal component. The vector, `latent`, stores the variances of the four principal components.

Reconstruct the centered ingredients data.

```
Xcentered = score*coeff'
```

```
Xcentered =
```

```

-0.4615  -22.1538  -5.7692  30.0000
-6.4615  -19.1538   3.2308  22.0000
 3.5385   7.8462  -3.7692 -10.0000
 3.5385  -17.1538  -3.7692  17.0000
-0.4615   3.8462  -5.7692   3.0000
 3.5385   6.8462  -2.7692  -8.0000
-4.4615  22.8462   5.2308 -24.0000
-6.4615  -17.1538  10.2308  14.0000
-5.4615   5.8462   6.2308  -8.0000
13.5385  -1.1538  -7.7692  -4.0000
-6.4615  -8.1538  11.2308   4.0000
 3.5385  17.8462  -2.7692 -18.0000
 2.5385  19.8462  -3.7692 -18.0000

```

The new data in `Xcentered` is the original ingredients data centered by subtracting the column means from corresponding columns.

T-Squared Statistic

Find the Hotelling's T-squared statistic values.

Load the sample data set.

```
load hald
```

The ingredients data has 13 observations for 4 variables.

Perform the principal component analysis and request the T-squared values.

```
[coeff,score,latent,tsquared] = pca(ingredients);  
tsquared
```

```
tsquared =
```

```
    5.6803  
    3.0758  
    6.0002  
    2.6198  
    3.3681  
    0.5668  
    3.4818  
    3.9794  
    2.6086  
    7.4818  
    4.1830  
    2.2327  
    2.7216
```

Request only the first two principal components and compute the T-squared values in the reduced space of requested principal components.

```
[coeff,score,latent,tsquared] = pca(ingredients,'NumComponents',2);
```

```
tsquared
```

```
tsquared =
```

```
    5.6803  
    3.0758  
    6.0002  
    2.6198  
    3.3681  
    0.5668
```

```
3.4818
3.9794
2.6086
7.4818
4.1830
2.2327
2.7216
```

Note that even when you specify a reduced component space, `pca` computes the T-squared values in the full space, using all four components.

The T-squared value in the reduced space corresponds to the Mahalanobis distance in the reduced space.

```
tsqreduced = mahal(score,score)
```

```
tsqreduced =
```

```
3.3179
2.0079
0.5874
1.7382
0.2955
0.4228
3.2457
2.6914
1.3619
2.9903
2.4371
1.3788
1.5251
```

Calculate the T-squared values in the discarded space by taking the difference of the T-squared values in the full space and Mahalanobis distance in the reduced space.

```
tsqdiscarded = tsquared - tsqreduced
```

```
tsqdiscarded =  
  
    2.3624  
    1.0679  
    5.4128  
    0.8816  
    3.0726  
    0.1440  
    0.2362  
    1.2880  
    1.2467  
    4.4915  
    1.7459  
    0.8539  
    1.1965
```

Percent Variability Explained by Principal Components

Find the percent variability explained by the principal components.

Load the sample data set.

```
load imports-85
```

Data matrix X has 13 continuous variables in columns 3 to 15: wheel-base, length, width, height, curb-weight, engine-size, bore, stroke, compression-ratio, horsepower, peak-rpm, city-mpg, and highway-mpg.

Find the percent variability explained by principal components of these variables.

```
[coeff,score,latent,tsquared,explained] = pca(X(:,3:15));
```

```
explained
```

```
explained =
```

```
    64.3429  
    35.4484
```



```
0.1550
0.0379
0.0078
0.0048
0.0013
0.0011
0.0005
0.0002
0.0002
0.0000
0.0000
```

The first two components explain 99.79% of all variability.

To skip any of the outputs, you can use ~ instead in the corresponding element. For example, if you don't want to get the T-squared values, specify

```
[coeff,score,latent,~,explained] = pca(X(:,3:15));
```

PCA in the Presence of Missing Data

Find the principal component coefficients when there are missing values in a data set.

Load the sample data set.

```
load imports-85
```

Data matrix X has 13 continuous variables in columns 3 to 15: wheel-base, length, width, height, curb-weight, engine-size, bore, stroke, compression-ratio, horsepower, peak-rpm, city-mpg, and highway-mpg. The variables bore and stroke are missing four values in rows 56 to 59, and the variables horsepower and peak-rpm are missing two values in rows 131 and 132.

Perform the principal component analysis.

```
[coeff,score,latent,tsquared,explained] = pca(X(:,3:15));
```

By default, `pca` performs the action specified by the `'Rows'`, `'complete'` name-value pair. This option removes the observations with NaN values before calculation. Rows of NaNs are inserted back into `score` and `tsquared` at the corresponding locations, namely rows 56 to 59, 131, and 132.

Use the `'pairwise'` option to perform the principal component analysis.

```
[coeff,score,latent,tsquared,explained] = pca(X(:,3:15),'Rows','pairwise')
```

In this case, `pca` computes the (i,j) element of the covariance matrix using the rows with no NaN values in the columns i or j of X . Note that the resulting covariance matrix might not be positive definite. This option applies when the algorithm `pca` uses is eigenvalue decomposition. When you don't specify the algorithm, as in this example, `pca` sets it to `'eig'`. If you require `'svd'` as the algorithm, with the `'pairwise'` option, then `pca` returns a warning message, sets the algorithm to `'eig'` and continues.

If you use the `'Rows'`, `'all'` name-value pair option, `pca` terminates because this option assumes there are no missing values in the data set.

```
[coeff,score,latent,tsquared,explained] = pca(X(:,3:15),'Rows','all');
```

```
Error using pca (line 180)  
Raw data contains NaN missing value while 'Rows' option is set to 'all'.
```

Weighted PCA

Use the inverse variable variances as weights while performing the principal components analysis.

Load the sample data set.

```
load hald
```

Perform the principal component analysis using the inverse of variances of the ingredients as variable weights.

```
[wcoeff,~,latent,~,explained] = pca(ingredients,'VariableWeights','var')
```

```
wcoeff =
```

```
-2.7998    2.9940   -3.9736    1.4180  
-8.7743   -6.4411    4.8927    9.9863  
 2.5240   -3.8749   -4.0845    1.7196  
 9.1714    7.5529    3.2710   11.3273
```

```
latent =
```

```
 2.2357  
 1.5761  
 0.1866  
 0.0016
```

```
explained =
```

```
55.8926  
39.4017  
 4.6652  
 0.0406
```

Note that the coefficient matrix, `wcoeff`, is not orthonormal.

Calculate the orthonormal coefficient matrix.

```
coefforth = inv(diag(std(ingredients))) * wcoeff
```

```
coefforth =
```

```
-0.4760    0.5090   -0.6755    0.2411  
-0.5639   -0.4139    0.3144    0.6418  
 0.3941   -0.6050   -0.6377    0.2685  
 0.5479    0.4512    0.1954    0.6767
```

Check orthonormality of the new coefficient matrix, `coefforth`.

```
coefforth*coefforth'
```

```
ans =
```

```

1.0000    0.0000   -0.0000   -0.0000
0.0000    1.0000   -0.0000   -0.0000
-0.0000   -0.0000    1.0000    0
-0.0000   -0.0000    0         1.0000
```

Definitions

Hotelling's T-squared Statistic

Hotelling's T-squared statistic is a statistical measure of the multivariate distance of each observation from the center of the data set. Even when you request fewer components than the number of variables, `pca` uses all principal components to compute the T-squared statistic (computes it in the full space). If you want the T-squared statistic in the reduced or the discarded space, do one of the following:

- For the T-squared statistic in the reduced space, use `mahal(score, score)`.
- For the T-squared statistic in the discarded space, first compute the T-squared statistic using `[coeff, score, latent, tsquared] = pca(X, 'NumComponents', k, ...)`, compute the T-squared statistic in the reduced space using `tsqreduced = mahal(score, score)`, and then take the difference: `tsquared - tsqreduced`.

Degrees of Freedom

The degrees of freedom, d , is equal to $n - 1$, if data is centered and n otherwise, where:

- n is the number of rows without any NaNs if you use `'Rows', 'complete'`.
- n is the number of rows without any NaNs in the column pair that has the maximum number of rows without NaNs if you use `'Rows', 'pairwise'`.

Variable Weights

Note that when variable weights are used, the coefficient matrix is not orthonormal. Suppose the variable weights vector you used is called `varwei`, and the principal component coefficients vector `pca` returned is `wcoeff`. You can calculate the orthonormal coefficients by using the transformation `diag(sqrt(varwei))*wcoeff`.

References

- [1] Jolliffe, I. T. *Principal Component Analysis*, 2nd ed., Springer, 2002.
- [2] Krzanowski, W. J. *Principles of Multivariate Analysis*, Oxford University Press, 1988.
- [3] Seber, G. A. F. *Multivariate Observations*, Wiley, 1984.
- [4] Jackson, J. E. A. *User's Guide to Principal Components*, Wiley, 1988.

See Also

`barttest` | `biplot` | `canoncorr` | `factoran` | `pcacov` | `pcares`
| `rotatefactors`

Related Examples

- “Quality of Life in U.S. Cities” on page 10-33

Concepts

- “Principal Component Analysis (PCA)” on page 10-31

Purpose Principal component analysis on covariance matrix

Syntax
COEFF = pcacov(V)
[COEFF,latent] = pcacov(V)
[COEFF,latent,explained] = pcacov(V)

Description COEFF = pcacov(V) performs principal components analysis on the p-by-p covariance matrix V and returns the principal component coefficients, also known as loadings. COEFF is a p-by-p matrix, with each column containing coefficients for one principal component. The columns are in order of decreasing component variance.

pcacov does not standardize V to have unit variances. To perform principal components analysis on standardized variables, use the correlation matrix $R = V ./ (SD * SD')$, where $SD = \text{sqrt}(\text{diag}(V))$, in place of V. To perform principal components analysis directly on the data matrix, use `pca`.

[COEFF,latent] = pcacov(V) returns latent, a vector containing the principal component variances, that is, the eigenvalues of V.

[COEFF,latent,explained] = pcacov(V) returns explained, a vector containing the percentage of the total variance explained by each principal component.

Examples

```
load hald
covx = cov(ingredients);
[COEFF,latent,explained] = pcacov(covx)
COEFF =
    0.0678 -0.6460  0.5673 -0.5062
    0.6785 -0.0200 -0.5440 -0.4933
   -0.0290  0.7553  0.4036 -0.5156
   -0.7309 -0.1085 -0.4684 -0.4844

latent =
    517.7969
     67.4964
     12.4054
```

0.2372

explained =

86.5974

11.2882

2.0747

0.0397

References

[1] Jackson, J. E. *A User's Guide to Principal Components*. Hoboken, NJ: John Wiley and Sons, 1991.

[2] Jolliffe, I. T. *Principal Component Analysis*. 2nd ed., New York: Springer-Verlag, 2002.

[3] Krzanowski, W. J. *Principles of Multivariate Analysis: A User's Perspective*. New York: Oxford University Press, 1988.

[4] Seber, G. A. F., *Multivariate Observations*, Wiley, 1984.

See Also

barttest | biplot | factoran | pcares | pca | rotatefactors

Purpose Residuals from principal component analysis

Syntax `residuals = pcares(X,ndim)`
`[residuals,reconstructed] = pcares(X,ndim)`

Description `residuals = pcares(X,ndim)` returns the residuals obtained by retaining `ndim` principal components of the `n`-by-`p` matrix `X`. Rows of `X` correspond to observations, columns to variables. `ndim` is a scalar and must be less than or equal to `p`. `residuals` is a matrix of the same size as `X`. Use the data matrix, *not* the covariance matrix, with this function.

`pcares` does not normalize the columns of `X`. To perform the principal components analysis based on standardized variables, that is, based on correlations, use `pcares(zscore(X), ndim)`. You can perform principal components analysis directly on a covariance or correlation matrix, but without constructing residuals, by using `pcacov`.

`[residuals,reconstructed] = pcares(X,ndim)` returns the reconstructed observations; that is, the approximation to `X` obtained by retaining its first `ndim` principal components.

Examples

This example shows the drop in the residuals from the first row of the Hald data as the number of component dimensions increases from one to three.

```
load hald
r1 = pcares(ingredients,1);
r2 = pcares(ingredients,2);
r3 = pcares(ingredients,3);

r11 = r1(1,:)
r11 =
    2.0350    2.8304   -6.8378    3.0879

r21 = r2(1,:)
r21 =
   -2.4037    2.6930   -1.6482    2.3425
```



```
r31 = r3(1,:)
r31 =
    0.2008    0.1957    0.2045    0.1921
```

References

- [1] Jackson, J. E., *A User's Guide to Principal Components*, John Wiley and Sons, 1991.
- [2] Jolliffe, I. T., *Principal Component Analysis*, 2nd Edition, Springer, 2002.
- [3] Krzanowski, W. J. *Principles of Multivariate Analysis: A User's Perspective*. New York: Oxford University Press, 1988.
- [4] Seber, G. A. F. *Multivariate Observations*. Hoboken, NJ: John Wiley & Sons, Inc., 1984.

See Also

factoran | pcacov | pca

gmdistribution.PComponents property

Purpose Input vector of mixing proportions

Description Optional input vector of mixing proportions p , or its default value.

Purpose

Probability density functions

Syntax

```
Y = pdf(name,X,A)
Y = pdf(name,X,A,B)
Y = pdf(name,X,A,B,C)
```

Description

`Y = pdf(name,X,A)` computes the probability density function for the one-parameter family of distributions specified by `name`. Parameter values for the distribution are given in `A`. Densities are evaluated at the values in `X` and returned in `Y`.

If `X` and `A` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A`. If `A` is a scalar, it is expanded to a constant matrix the same size as `X`.

`Y` is the common size of `X` and `A` after any necessary scalar expansion.

`Y = pdf(name,X,A,B)` computes the probability density function for two-parameter families of distributions, where parameter values are given in `A` and `B`.

If `X`, `A`, and `B` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A` and `B`. If either `A` or `B` are scalars, they are expanded to constant matrices the same size as `X`.

`Y` is the common size of `X`, `A`, and `B` after any necessary scalar expansion.

`Y = pdf(name,X,A,B,C)` computes the probability density function for three-parameter families of distributions, where parameter values are given in `A`, `B`, and `C`.

If `X`, `A`, `B`, and `C` are arrays, they must be the same size. If `X` is a scalar, it is expanded to a constant matrix the same size as `A`, `B`, and `C`. If any of `A`, `B` or `C` are scalars, they are expanded to constant matrices the same size as `X`.

`Y` is the common size of `X`, `A`, `B` and `C` after any necessary scalar expansion.

Acceptable strings for `name` are:

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'beta' or 'Beta'	“Beta Distribution” on page B-4	a	b	—
'bino' or 'Binomial'	“Binomial Distribution” on page B-7	n: number of trials	p: probability of success for each trial	—
'birnbaumsaunders'	“Birnbaum-Saunders Distribution” on page B-10	θ	γ	—
'burr' or 'Burr':	“Burr Type XII Distribution” on page B-12	α : scale parameter	c: shape parameter	k: shape parameter
'chi2' or 'Chisquare'	“Chi-Square Distribution” on page B-25	ν : degrees of freedom	—	—
'exp' or 'Exponential'	“Exponential Distribution” on page B-29	μ : mean	—	—
'ev' or 'Extreme Value'	“Extreme Value Distribution” on page B-32	μ : location parameter	σ : scale parameter	—
'f' or 'F'	“F Distribution” on page B-38	ν_1 : numerator degrees of freedom	ν_2 : denominator degrees of freedom	—
'gam' or 'Gamma'	“Gamma Distribution” on page B-40	a: shape parameter	b: scale parameter	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'gev' or 'Generalized Extreme Value'	“Generalized Extreme Value Distribution” on page B-45	k: shape parameter	σ : scale parameter	μ : location parameter
'gp' or 'Generalized Pareto'	“Generalized Pareto Distribution” on page B-50	k: tail index (shape) parameter	σ : scale parameter	μ : threshold (location) parameter
'geo' or 'Geometric'	“Geometric Distribution” on page B-54	p : probability parameter	—	—
'hyge' or 'Hypergeometric'	“Hypergeometric Distribution” on page B-56	M: size of the population	K: number of items with the desired characteristic in the population	n: number of samples drawn
'inversegaussian'	“Inverse Gaussian Distribution” on page B-58	μ	λ	—
'logistic'	“Logistic Distribution” on page B-62	μ	σ	—
'loglogistic'	“Loglogistic Distribution” on page B-63	μ	σ	—
'logn' or 'Lognormal'	“Lognormal Distribution” on page B-64	μ	σ	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'nakagami'	“Nakagami Distribution” on page B-83	μ	ω	—
'nbin' or 'Negative Binomial'	“Negative Binomial Distribution” on page B-85	r: number of successes	p: probability of success in a single trial	—
'ncf' or 'Noncentral F'	“Noncentral F Distribution” on page B-91	v1: numerator degrees of freedom	v2: denominator degrees of freedom	δ : noncentrality parameter
'nct' or 'Noncentral t'	“Noncentral t Distribution” on page B-93	v: degrees of freedom	δ : noncentrality parameter	—
'ncx2' or 'Noncentral Chi-square'	“Noncentral Chi-Square Distribution” on page B-89	v: degrees of freedom	δ : noncentrality parameter	—
'norm' or 'Normal'	“Normal Distribution” on page B-96	μ : mean	σ : standard deviation	—
'poiss' or 'Poisson'	“Poisson Distribution” on page B-102	λ : mean	—	—
'rayl' or 'Rayleigh'	“Rayleigh Distribution” on page B-104	b: scale parameter	—	—
'rician'	“Rician Distribution” on page B-106	s: noncentrality parameter	σ : scale parameter	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
't' or 'T'	“Student’s t Distribution” on page B-108	ν : degrees of freedom	—	—
'tlocationscale'	“t Location-Scale Distribution” on page B-110	μ : location parameter	σ : scale parameter	ν : shape parameter
'unif' or 'Uniform'	“Uniform Distribution (Continuous)” on page B-112	a: lower endpoint (minimum)	b: upper endpoint (maximum)	—
'unid' or 'Discrete Uniform'	“Uniform Distribution (Discrete)” on page B-114	N: maximum observable value	—	—
'wbl' or 'Weibull'	“Weibull Distribution” on page B-116	a: scale parameter	b: shape parameter	—

Examples

Compute the pdf of the normal distribution with mean 0 and standard deviation 1 at inputs $-2, -1, 0, 1, 2$:

```
p1 = pdf('Normal', -2:2, 0, 1)
p1 =
    0.0540    0.2420    0.3989    0.2420    0.0540
```

The order of the parameters is the same as for `normpdf`.

Compute the pdfs of Poisson distributions with rate parameters 0, 1, ..., 4 at inputs 1, 2, ..., 5, respectively:

```
p2 = pdf('Poisson', 0:4, 1:5)
```

```
p2 =  
0.3679 0.2707 0.2240 0.1954 0.1755
```

The order of the parameters is the same as for `poisspdf`.

See Also

`cdf` | `icdf` | `mle` | `random`

Purpose Probability density function for Gaussian mixture distribution

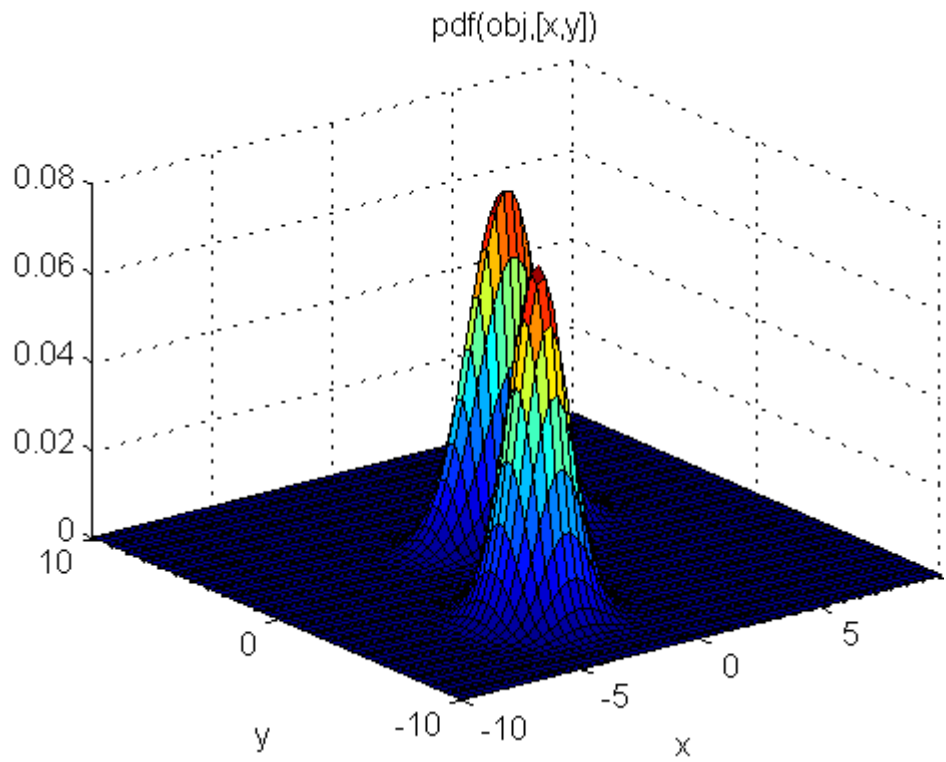
Syntax `y = pdf(obj,X)`

Description `y = pdf(obj,X)` returns a vector `y` of length n containing the values of the probability density function (`pdf`) for the `gmdistribution` object `obj`, evaluated at the n -by- d data matrix `X`, where n is the number of observations and d is the dimension of the data. `obj` is an object created by `gmdistribution` or `fit`. `y(I)` is the pdf of observation `I`.

Examples Create a `gmdistribution` object defining a two-component mixture of bivariate Gaussian distributions:

```
MU = [1 2;-3 -5];  
SIGMA = cat(3,[2 0;0 .5],[1 0;0 1]);  
p = ones(1,2)/2;  
obj = gmdistribution(MU,SIGMA,p);  
  
ezsurf(@(x,y)pdf(obj,[x y]),[-10 10],[-10 10])
```

gmdistribution.pdf



See Also

[gmdistribution](#) | [fit](#) | [cdf](#) | [mvnpdf](#)

Purpose Probability density function for piecewise distribution

Syntax `P = pdf(obj,X)`

Description `P = pdf(obj,X)` returns an array `P` of values of the probability density function for the piecewise distribution object `obj`, evaluated at the values in the array `X`.

Note For a Pareto tails object, the pdf is computed using the generalized Pareto distribution in the tails. In the center, the pdf is computed using the slopes of the cdf, which are interpolated between a set of discrete values. Therefore the pdf in the center is piecewise constant. It is noisy for a `cdf` specified in `paretotails` via the `'ecdf'` option, and somewhat smoother for the `'kernel'` option, but generally not a good estimate of the underlying density of the original data.

Examples Fit Pareto tails to a t distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);
obj = paretotails(t,0.1,0.9);
[p,q] = boundary(obj)
p =
    0.1000
    0.9000
q =
   -1.7766
    1.8432

pdf(obj,q)
ans =
    0.2367
    0.1960
```

piecewisedistribution.pdf

See Also

[paretotails](#) | [cdf](#)

Purpose	Return probability density function (PDF) for ProbDist object	
Syntax	$Y = \text{pdf}(PD, X)$	
Description	$Y = \text{pdf}(PD, X)$ returns Y , an array containing the probability density function (PDF) for the ProbDist object PD , evaluated at values in X .	
Input Arguments	PD	An object of the class ProbDistUnivParam or ProbDistUnivKernel.
	X	A numeric array of values where you want to evaluate the PDF.
Output Arguments	Y	An array containing the probability density function (PDF) for the ProbDist object PD .
See Also	pdf	

pdist

Purpose Pairwise distance between pairs of objects

Syntax
`D = pdist(X)`
`D = pdist(X, distance)`

Description `D = pdist(X)` computes the Euclidean distance between pairs of objects in m -by- n data matrix X . Rows of X correspond to observations, and columns correspond to variables. D is a row vector of length $m(m-1)/2$, corresponding to pairs of observations in X . The distances are arranged in the order $(2,1)$, $(3,1)$, ..., $(m,1)$, $(3,2)$, ..., $(m,2)$, ..., $(m,m-1)$. D is commonly used as a dissimilarity matrix in clustering or multidimensional scaling.

To save space and computation time, D is formatted as a vector. However, you can convert this vector into a square matrix using the `squareform` function so that element i, j in the matrix, where $i < j$, corresponds to the distance between objects i and j in the original data set.

`D = pdist(X, distance)` computes the distance between objects in the data matrix, X , using the method specified by `distance`, which can be any of the following character strings.

Metric	Description
'euclidean'	Euclidean distance (default).
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between rows in X is scaled by dividing by the corresponding element of the standard deviation <code>S=nanstd(X)</code> . To specify another value for S , use <code>D=pdist(X, 'seuclidean', S)</code> .
'cityblock'	City block metric.
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use <code>D = pdist(X, 'minkowski', P)</code> , where P is a scalar positive value of the exponent.

Metric	Description
'chebychev'	Chebychev distance (maximum coordinate difference).
'mahalanobis'	Mahalanobis distance, using the sample covariance of X as computed by nancov. To compute the distance with a different covariance, use <code>D = pdist(X, 'mahalanobis', C)</code> , where the matrix C is symmetric and positive definite.
'cosine'	One minus the cosine of the included angle between points (treated as vectors).
'correlation'	One minus the sample correlation between points (treated as sequences of values).
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
'hamming'	Hamming distance, which is the percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, which is the percentage of nonzero coordinates that differ.
custom distance function	<p>A distance function specified using @: <code>D = pdist(X,@distfun)</code></p> <p>A distance function must be of form</p> $d2 = \text{distfun}(XI, XJ)$ <p>taking as arguments a 1-by-<i>n</i> vector XI, corresponding to a single row of X, and an <i>m2</i>-by-<i>n</i> matrix XJ, corresponding to multiple rows of X. <code>distfun</code> must accept a matrix XJ with an arbitrary number of rows. <code>distfun</code> must return an <i>m2</i>-by-1 vector of distances d2, whose <i>k</i>th element is the distance between XI and XJ(<i>k</i>, :).</p>

The output D is arranged in the order of $((2,1),(3,1),\dots,(m,1),(3,2),\dots(m,2),\dots(m,m-1))$, i.e. the lower left triangle of the full m -by- m distance matrix in column order. To get the distance between the i th and j th observations ($i < j$), either use the formula $D((i-1)*(m-i/2)+j-i)$, or use the helper function $Z = \text{squareform}(D)$, which returns an m -by- m square symmetric matrix, with the (i,j) entry equal to distance between observation i and observation j .

Metrics

Given an m -by- n data matrix X , which is treated as m (1-by- n) row vectors x_1, x_2, \dots, x_m , the various distances between the vector x_s and x_t are defined as follows:

- Euclidean distance

$$d_{st}^2 = (x_s - x_t)(x_s - x_t)'$$

Notice that the Euclidean distance is a special case of the Minkowski metric, where $p = 2$.

- Standardized Euclidean distance

$$d_{st}^2 = (x_s - x_t)V^{-1}(x_s - x_t)'$$

where V is the n -by- n diagonal matrix whose j th diagonal element is $S(j)^2$, where S is the vector of standard deviations.

- Mahalanobis distance

$$d_{st}^2 = (x_s - x_t)C^{-1}(x_s - x_t)'$$

where C is the covariance matrix.

- City block metric

$$d_{st} = \sum_{j=1}^n |x_{sj} - x_{tj}|$$

Notice that the city block distance is a special case of the Minkowski metric, where $p=1$.

- Minkowski metric

$$d_{st} = \sqrt[p]{\sum_{j=1}^n |x_{sj} - x_{tj}|^p}$$

Notice that for the special case of $p = 1$, the Minkowski metric gives the city block metric, for the special case of $p = 2$, the Minkowski metric gives the Euclidean distance, and for the special case of $p = \infty$, the Minkowski metric gives the Chebychev distance.

- Chebychev distance

$$d_{st} = \max_j \{|x_{sj} - x_{tj}|\}$$

Notice that the Chebychev distance is a special case of the Minkowski metric, where $p = \infty$.

- Cosine distance

$$d_{st} = 1 - \frac{x_s x_t'}{\sqrt{(x_s x_s')(x_t x_t')}}}$$

- Correlation distance

$$d_{st} = 1 - \frac{(x_s - \bar{x}_s)(x_t - \bar{x}_t)'}{\sqrt{(x_s - \bar{x}_s)(x_s - \bar{x}_s)' (x_t - \bar{x}_t)(x_t - \bar{x}_t)'}}$$

where

$$\bar{x}_s = \frac{1}{n} \sum_j x_{sj} \quad \text{and} \quad \bar{x}_t = \frac{1}{n} \sum_j x_{tj}$$

- Hamming distance

$$d_{st} = (\#(x_{sj} \neq x_{tj}) / n)$$

- Jaccard distance

$$d_{st} = \frac{\#[(x_{sj} \neq x_{tj}) \cap ((x_{sj} \neq 0) \cup (x_{tj} \neq 0))]}{\#[(x_{sj} \neq 0) \cup (x_{tj} \neq 0)]}$$

- Spearman distance

$$d_{st} = 1 - \frac{(r_s - \bar{r}_s)(r_t - \bar{r}_t)'}{\sqrt{(r_s - \bar{r}_s)(r_s - \bar{r}_s)'} \sqrt{(r_t - \bar{r}_t)(r_t - \bar{r}_t)'}}$$

where

- r_{sj} is the rank of x_{sj} taken over $x_{1j}, x_{2j}, \dots, x_{mj}$, as computed by `tiedrank`
- r_s and r_t are the coordinate-wise rank vectors of x_s and x_t , i.e.,
 $r_s = (r_{s1}, r_{s2}, \dots, r_{sn})$

$$\bar{r}_s = \frac{1}{n} \sum_j r_{sj} = \frac{(n+1)}{2}$$

$$\bar{r}_t = \frac{1}{n} \sum_j r_{tj} = \frac{(n+1)}{2}$$

Examples

Generate random data and find the unweighted Euclidean distance and then find the weighted distance using two different methods:

```
% Compute the ordinary Euclidean distance.
X = randn(100, 5);
D = pdist(X, 'euclidean'); % euclidean distance
```

```
% Compute the Euclidean distance with each coordinate
% difference scaled by the standard deviation.
```

```
Dstd = pdist(X,'seuclidean');

% Use a function handle to compute a distance that weights
% each coordinate contribution differently.
Wgts = [.1 .3 .3 .2 .1];      % coordinate weights
weuc = @(XI,XJ,W)(sqrt(bsxfun(@minus,XI,XJ).^2 * W'));
Dwgt = pdist(X, @(Xi,Xj) weuc(Xi,Xj,Wgts));
```

See Also

[cluster](#) | [clusterdata](#) | [cmdscales](#) | [cophenet](#) | [dendrogram](#) | [inconsistent](#) | [linkage](#) | [pdist2](#) | [silhouette](#) | [squareform](#)

pdist2

Purpose

Pairwise distance between two sets of observations

Syntax

```
D = pdist2(X,Y)
D = pdist2(X,Y,distance)
D = pdist2(X,Y,'minkowski',P)
D = pdist2(X,Y,'mahalanobis',C)
D = pdist2(X,Y,distance,'Smallest',K)
D = pdist2(X,Y,distance,'Largest',K)
[D,I] = pdist2(X,Y,distance,'Smallest',K)
[D,I] = pdist2(X,Y,distance,'Largest',K)
```

Description

`D = pdist2(X,Y)` returns a matrix `D` containing the Euclidean distances between each pair of observations in the mx -by- n data matrix `X` and my -by- n data matrix `Y`. Rows of `X` and `Y` correspond to observations, columns correspond to variables. `D` is an mx -by- my matrix, with the (i,j) entry equal to distance between observation i in `X` and observation j in `Y`. The (i,j) entry will be NaN if observation i in `X` or observation j in `Y` contain NaNs.

`D = pdist2(X,Y,distance)` computes `D` using `distance`. Choices are:

Metric	Description
'euclidean'	Euclidean distance (default).
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between rows in <code>X</code> and <code>Y</code> is scaled by dividing by the corresponding element of the standard deviation computed from <code>X</code> , <code>S=nanstd(X)</code> . To specify another value for <code>S</code> , use <code>D = PDIST2(X,Y,'seuclidean',S)</code> .
'cityblock'	City block metric.
'minkowski'	Minkowski distance. The default exponent is 2. To compute the distance with a different exponent, use <code>D = pdist2(X,Y,'minkowski',P)</code> , where the exponent <code>P</code> is a scalar positive value.

Metric	Description
'chebychev'	Chebychev distance (maximum coordinate difference).
'mahalanobis'	Mahalanobis distance, using the sample covariance of X as computed by nancov. To compute the distance with a different covariance, use $D = \text{pdist2}(X, Y, \text{'mahalanobis'}, C)$ where the matrix C is symmetric and positive definite.
'cosine'	One minus the cosine of the included angle between points (treated as vectors).
'correlation'	One minus the sample correlation between points (treated as sequences of values).
'spearman'	One minus the sample Spearman's rank correlation between observations, treated as sequences of values.
'hamming'	Hamming distance, the percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, the percentage of nonzero coordinates that differ.
function	<p>A distance function specified using @: $D = \text{pdist2}(X, Y, @\text{distfun})$.</p> <p>A distance function must be of the form</p> <pre>function D2 = distfun(ZI, ZJ)</pre> <p>taking as arguments a 1-by-n vector ZI containing a single observation from X or Y, an m2-by-n matrix ZJ containing multiple observations from X or Y, and returning an m2-by-1 vector of distances D2, whose Jth element is the distance between the observations ZI and ZJ(J, :).</p>

Metric	Description
	If your data is not sparse, generally it is faster to use a built-in distance than to use a function handle.

$D = \text{pdist2}(X,Y,\text{distance},\text{'Smallest'},K)$ returns a K -by- m_y matrix D containing the K smallest pairwise distances to observations in X for each observation in Y . pdist2 sorts the distances in each column of D in ascending order. $D = \text{pdist2}(X,Y,\text{distance},\text{'Largest'},K)$ returns the K largest pairwise distances sorted in descending order. If K is greater than m_x , pdist2 returns an m_x -by- m_y distance matrix. For each observation in Y , pdist2 finds the K smallest or largest distances by computing and comparing the distance values to all the observations in X .

$[D,I] = \text{pdist2}(X,Y,\text{distance},\text{'Smallest'},K)$ returns a K -by- m_y matrix I containing indices of the observations in X corresponding to the K smallest pairwise distances in D . $[D,I] = \text{pdist2}(X,Y,\text{distance},\text{'Largest'},K)$ returns indices corresponding to the K largest pairwise distances.

Metrics

Given an m_x -by- n data matrix X , which is treated as m_x (1-by- n) row vectors x_1, x_2, \dots, x_{m_x} , and m_y -by- n data matrix Y , which is treated as m_y (1-by- n) row vectors y_1, y_2, \dots, y_{m_y} , the various distances between the vector x_s and y_t are defined as follows:

- Euclidean distance

$$d_{st}^2 = (x_s - y_t)(x_s - y_t)'$$

Notice that the Euclidean distance is a special case of the Minkowski metric, where $p=2$.

- Standardized Euclidean distance

$$d_{st}^2 = (x_s - y_t)V^{-1}(x_s - y_t)'$$

where V is the n -by- n diagonal matrix whose j th diagonal element is $S(j)^2$, where S is the vector of standard deviations.

- Mahalanobis distance

$$d_{st}^2 = (x_s - y_t)C^{-1}(x_s - y_t)'$$

where C is the covariance matrix.

- City block metric

$$d_{st} = \sum_{j=1}^n |x_{sj} - y_{tj}|$$

Notice that the city block distance is a special case of the Minkowski metric, where $p=1$.

- Minkowski metric

$$d_{st} = \sqrt[p]{\sum_{j=1}^n |x_{sj} - y_{tj}|^p}$$

Notice that for the special case of $p = 1$, the Minkowski metric gives the City Block metric, for the special case of $p = 2$, the Minkowski metric gives the Euclidean distance, and for the special case of $p=\infty$, the Minkowski metric gives the Chebychev distance.

- Chebychev distance

$$d_{st} = \max_j \{|x_{sj} - y_{tj}|\}$$

Notice that the Chebychev distance is a special case of the Minkowski metric, where $p=\infty$.

- Cosine distance

$$d_{st} = \left(1 - \frac{x_s y_t'}{\sqrt{(x_s x_s')(y_t y_t')}} \right)$$

- Correlation distance

$$d_{st} = 1 - \frac{(x_s - \bar{x}_s)(y_t - \bar{y}_t)'}{\sqrt{(x_s - \bar{x}_s)(x_s - \bar{x}_s)'(y_t - \bar{y}_t)(y_t - \bar{y}_t)'}}$$

where

$$\bar{x}_s = \frac{1}{n} \sum_j x_{sj} \quad \text{and}$$
$$\bar{y}_t = \frac{1}{n} \sum_j y_{tj}$$

- Hamming distance

$$d_{st} = (\#(x_{sj} \neq y_{tj}) / n)$$

- Jaccard distance

$$d_{st} = \frac{\#[(x_{sj} \neq y_{tj}) \cap ((x_{sj} \neq 0) \cup (y_{tj} \neq 0))]}{\#[(x_{sj} \neq 0) \cup (y_{tj} \neq 0)]}$$

- Spearman distance

$$d_{st} = 1 - \frac{(r_s - \bar{r}_s)(r_t - \bar{r}_t)'}{\sqrt{(r_s - \bar{r}_s)(r_s - \bar{r}_s)'(r_t - \bar{r}_t)(r_t - \bar{r}_t)'}}$$

where

- r_{sj} is the rank of x_{sj} taken over $x_{1j}, x_{2j}, \dots, x_{mx,j}$, as computed by `tiedrank`
- r_{tj} is the rank of y_{tj} taken over $y_{1j}, y_{2j}, \dots, y_{my,j}$, as computed by `tiedrank`
- r_s and r_t are the coordinate-wise rank vectors of x_s and y_t , i.e. $r_s = (r_{s1}, r_{s2}, \dots, r_{sn})$ and $r_t = (r_{t1}, r_{t2}, \dots, r_{tn})$
- $\bar{r}_s = \frac{1}{n} \sum_j r_{sj} = \frac{(n+1)}{2}$
- $\bar{r}_t = \frac{1}{n} \sum_j r_{tj} = \frac{(n+1)}{2}$

Examples

Generate random data and find the unweighted Euclidean distance, then find the weighted distance using two different methods:

```
% Compute the ordinary Euclidean distance
X = randn(100, 5);
Y = randn(25, 5);
D = pdist2(X,Y,'euclidean'); % euclidean distance

% Compute the Euclidean distance with each coordinate
% difference scaled by the standard deviation
Dstd = pdist2(X,Y,'seuclidean');

% Use a function handle to compute a distance that weights
% each coordinate contribution differently.
Wgts = [.1 .3 .3 .2 .1];
weuc = @(XI,XJ,W)(sqrt(bsxfun(@minus,XI,XJ).^2 * W'));
Dwgt = pdist2(X,Y, @(Xi,Xj) weuc(Xi,Xj,Wgts));
```

See Also

`pdist` | `createns` | `knnsearch` | `KDTreeSearcher` | `ExhaustiveSearcher`

pearsrnd

Purpose

Pearson system random numbers

Syntax

```
r = pearsrnd(mu,sigma,skew,kurt,m,n)
r = pearsrnd(mu,sigma,skew,kurt)
r = pearsrnd(mu,sigma,skew,kurt,m,n,...)
r = pearsrnd(mu,sigma,skew,kurt,[m,n,...])
[r,type] = pearsrnd(...)
[r,type,coefs] = pearsrnd(...)
```

Description

`r = pearsrnd(mu,sigma,skew,kurt,m,n)` returns an m -by- n matrix of random numbers drawn from the distribution in the Pearson system with mean `mu`, standard deviation `sigma`, skewness `skew`, and kurtosis `kurt`. The parameters `mu`, `sigma`, `skew`, and `kurt` must be scalars.

Note Because `r` is a random sample, its sample moments, especially the skewness and kurtosis, typically differ somewhat from the specified distribution moments.

`pearsrnd` uses the definition of kurtosis for which a normal distribution has a kurtosis of 3. Some definitions of kurtosis subtract 3, so that a normal distribution has a kurtosis of 0. The `pearsrnd` function does not use this convention.

Some combinations of moments are not valid; in particular, the kurtosis must be greater than the square of the skewness plus 1. The kurtosis of the normal distribution is defined to be 3.

`r = pearsrnd(mu,sigma,skew,kurt)` returns a scalar value.

`r = pearsrnd(mu,sigma,skew,kurt,m,n,...)` or `r = pearsrnd(mu,sigma,skew,kurt,[m,n,...])` returns an m -by- n -by-... array.

`[r,type] = pearsrnd(...)` returns the type of the specified distribution within the Pearson system. `type` is a scalar integer from 0

to 7. Set `m` and `n` to 0 to identify the distribution type without generating any random values.

The seven distribution types in the Pearson system correspond to the following distributions:

- 0 — Normal distribution
- 1 — Four-parameter beta distribution
- 2 — Symmetric four-parameter beta distribution
- 3 — Three-parameter gamma distribution
- 4 — Not related to any standard distribution. The density is proportional to:

$$(1 + ((x - a)/b)^2)^{-c} \exp(-d \arctan((x - a)/b)).$$

- 5 — Inverse gamma location-scale distribution
- 6 — F location-scale distribution
- 7 — Student's t location-scale distribution

`[r,type,coefs] = pearsrnd(...)` returns the coefficients `coefs` of the quadratic polynomial that defines the distribution via the differential equation

$$\frac{d}{dx} \log(p(x)) = \frac{-(a+x)}{c(0) + c(1)x + c(2)x^2}.$$

Examples

Generate random values from the standard normal distribution:

```
r = pearsrnd(0,1,0,3,100,1); % Equivalent to randn(100,1)
```

Determine the distribution type:

```
[r,type] = pearsrnd(0,1,1,4,0,0);
r =
    []
```

pearsrnd

type =
1

References

[1] Johnson, N.L., S. Kotz, and N. Balakrishnan (1994) Continuous Univariate Distributions, Volume 1, Wiley-Interscience, Pg 15, Eqn 12.33.

See Also

random | johnsrnd

Purpose

Compute Receiver Operating Characteristic (ROC) curve or other performance curve for classifier output

Syntax

```
[X,Y] = perfcurve(labels,scores,posclass)
[X,Y] = perfcurve(labels,scores,posclass,'Name',value)
[X,Y,T,AUC,OPTROCPT,SUBY,SUBYNAMES] = perfcurve(labels,scores,
    posclass)
[X,Y,T,AUC] = perfcurve(labels,scores,posclass)
```

Description

`[X,Y] = perfcurve(labels,scores,posclass)` computes a ROC curve for a vector of classifier predictions `scores` given true class labels, `labels`. `labels` can be a numeric vector, logical vector, character matrix, cell array of strings or categorical vector. `scores` is a numeric vector of scores returned by a classifier for some data. `posclass` is the positive class label (scalar), either numeric (for numeric labels), logical (for logical labels), or char. The returned values `X` and `Y` are coordinates for the performance curve and can be visualized with `plot(X,Y)`. For more information on `labels`, `scores`, and `posclass`, see “Input Arguments” on page 20-1709 . For more information on `X` and `Y`, see “Output Arguments” on page 20-1713.

`[X,Y] = perfcurve(labels,scores,posclass,'Name',value)` specifies one or more optional parameter name/value pairs, with `Name` in single quotes. See “Input Arguments” on page 20-1709 for a list of inputs, parameter name/value pairs, and respective explanations.

See “Grouping Variables” on page 2-72 for more information on grouping variables.

`[X,Y,T,AUC,OPTROCPT,SUBY,SUBYNAMES] = perfcurve(labels,scores,posclass)` returns:

- An array of thresholds on classifier scores for the computed values of `X` and `Y` (`T`).
- The area under curve (AUC) for the computed values of `X` and `Y`.
- The optimal operating point of the ROC curve (`OPTROCPT`).
- An array of `Y` values for negative subclasses (`SUBY`).

- A cell array of negative class names (SUBYNAMES).

For more information on each output, see “Output Arguments” on page 20-1713.

`[X,Y,T,AUC] = perfcurve(labels,scores,posclass)` also returns pointwise confidence bounds for the computed values X, Y, T, and AUC if you supply cell arrays for `labels` and `scores` or set `NBoot` (see “Input Arguments” on page 20-1709) to a positive integer. To compute the confidence bounds, `perfcurve` uses either vertical averaging (VA) or threshold averaging (TA). The returned values Y are an m -by-3 array in which the 1st element in every row gives the mean value, the 2nd element gives the lower bound and the 3rd element gives the upper bound. The returned AUC is a row-vector with 3 elements following the same convention. For VA, the returned values T are an m -by-3 array and X is a column-vector. For TA, the returned values X are an m -by-3 matrix and T is a column-vector.

`perfcurve` computes confidence bounds using either cross validation or bootstrap. If you supply cell arrays for `labels` and `scores`, `perfcurve` uses cross validation and treats elements in the cell arrays as cross validation folds. `labels` can be a cell array of numeric vectors, logical vectors, character matrices, cell arrays of strings or categorical vectors. All elements in `labels` must have the same type. `scores` is a cell array of numeric vectors. The cell arrays for `labels` and `scores` must have the same number of elements, and the number of labels in cell k must be equal to the number of scores in cell k for any k in the range from 1 to the number of elements in `scores`.

If you set `NBoot` to a positive integer, `perfcurve` generates `nboot` bootstrap replicas to compute pointwise confidence bounds. You cannot supply cell arrays for `labels` and `scores` and set `NBoot` to a positive integer at the same time.

`perfcurve` returns pointwise confidence bounds. It does not return a simultaneous confidence band for the entire curve.

If you use 'XCrit' or 'YCrit' options described below to set the criterion for X or Y to an anonymous function, `perfcurve` can only compute confidence bounds by bootstrap.

Input Arguments

labels	labels can be a numeric vector, logical vector, character matrix, cell array of strings or categorical vector.
scores	scores is a numeric vector of scores returned by a classifier for some data. This vector must have as many elements as labels does.
posclass	posclass is the positive class label (scalar), either numeric (for numeric labels) or char. The specified positive class must be in the array of input labels.

Name-Value Pair Arguments

Name

Value and Description

negClass

List of negative classes. Can be either a numeric array or an array of chars or a cell array of strings. By default, negClass is set to 'all' and all classes found in the input array of labels that are not the positive class are considered negative. If negClass is a subset of the classes found in the input array of labels, instances with labels that do not belong to either positive or negative classes are discarded.

xCrit

Criterion to compute for X. This criterion must be a monotone function of the positive class score. perfcurve supports the following criteria:

- TP — Number of true positive instances.
- FN — Number of false negative instances.
- FP — Number of false positive instances.
- TN — Number of true negative instances.
- TP+FP — Sum of TP and FP.

Name

Value and Description

- RPP — Rate of positive predictions.
 $RPP = (TP + FP) / (TP + FN + FP + TN)$
- RNP — Rate of negative predictions.
 $RNP = (TN + FN) / (TP + FN + FP + TN)$
- accu — Accuracy. $accu = (TP + TN) / (TP + FN + FP + TN)$
- TPR, sens, reca — True positive rate, sensitivity, recall. $TPR, sens, reca = TP / (TP + FN)$
- FNR, miss — False negative rate, miss. $FNR, miss = FN / (TP + FN)$
- FPR, fall — False positive rate, fallout. $FPR, fall = FP / (TN + FP)$
- TNR, spec — True negative rate, specificity. $TNR, spec = TN / (TN + FP)$
- PPV, prec — Positive predictive value, precision. $PPV, prec = TP / (TP + FP)$
- NPV — Negative predictive value. $NPV = TN / (TN + FN)$
- ecost — Expected cost.
 $ecost = (TP * COST(P|P) + FN * COST(N|P) + FP * COST(P|N) + TN * COST(N|N)) / (TP + FN + FP + TN)$

In addition, you can define an arbitrary criterion by supplying an anonymous function of three arguments, $(C, scale, cost)$, where C is a 2-by-2 confusion matrix, $scale$ is a 2-by-1 array of class scales, and $cost$ is a 2-by-2 misclassification cost matrix.

Caution Some of these criteria return NaN values at one of the two special thresholds, 'reject all' and 'accept all'.

Name	Value and Description
yCrit	Criterion to compute for Y. perfcurve supports the same criteria as for X. This criterion does not have to be a monotone function of the positive class score.
XVals	Values for the X criterion. The default value for xVals is 'all' and perfcurve computes X and Y values for all scores. If the value for xVals is not 'all', it must be a numeric array. In this case, perfcurve computes X and Y only for the specified xVals.
TVals	Thresholds for the positive class score. By default, TVals is unset and perfcurve computes X, Y, and T values for all scores. You can set TVals to either 'all' or a numeric array. If TVals is set to 'all' or unset and XVals is unset, perfcurve returns X, Y, and T values for all scores and computes pointwise confidence bounds for Y and X using threshold averaging. If TVals is set to a numeric array, perfcurve returns X, Y, and T values for the specified thresholds and computes pointwise confidence bounds for Y and X at these thresholds using threshold averaging. You cannot set XVals and TVals at the same time.
UseNearest	'on' to use nearest values found in the data instead of the specified numeric XVals or TVals and 'off' otherwise. If you specify numeric XVals and set UseNearest to 'on', perfcurve returns nearest unique values X found in the data, as well as corresponding values of Y and T. If you specify numeric XVals and set UseNearest to 'off', perfcurve returns these XVals sorted. By default this parameter is set to 'on'. If you compute confidence bounds by cross validation or bootstrap, this parameter is always 'off'.

Name	Value and Description
ProcessNaN	Specifies how perfcurve processes NaN scores. The default value is 'ignore' and perfcurve removes observations with NaN scores from the data. If you set the parameter to 'addtofalse', perfcurve adds instances with NaN scores to false classification counts in the respective class. That is, perfcurve always counts instances from the positive class as false negative (FN), and always counts instances from the negative class as false positive (FP).
Prior	Either string or array with two elements. It represents prior probabilities for the positive and negative class, respectively. Default is 'empirical', that is, perfcurve derives prior probabilities from class frequencies. If set to 'uniform', perfcurve sets all prior probabilities equal.
Cost	A 2-by-2 matrix of misclassification costs $[C(P P) \ C(N P); C(P N) \ C(N N)]$ where $C(I J)$ is the cost of misclassifying class J as class I . By default set to $[0 \ 0.5; \ 0.5 \ 0]$.
Alpha	A numeric value between 0 and 1. perfcurve returns $100*(1-Alpha)$ percent pointwise confidence bounds for X, Y, T and AUC. By default set to 0.05 for 95% confidence interval.
Weights	A numeric vector of nonnegative observation weights. This vector must have as many elements as scores or labels do. If you supply cell arrays for scores and labels and you need to supply weights, you must supply them as a cell array too. In this case, every element in weights must be a numeric vector with as many elements as the corresponding element in scores: <code>numel(weights{1})==numel(scores{1})</code> etc. To compute X, Y and T or to compute confidence bounds by cross validation, perfcurve uses these observation weights instead of observation counts. To compute confidence bounds by bootstrap, perfcurve samples N out of N with replacement using these weights as multinomial sampling probabilities.

Name	Value and Description
NBoot	Number of bootstrap replicas for computation of confidence bounds. Must be a positive integer. By default this parameter is set to zero, and bootstrap confidence bounds are not computed. If you supply cell arrays for <code>labels</code> and <code>scores</code> , this parameter must be set to zero because <code>perfcurve</code> cannot use both cross validation and bootstrap to compute confidence bounds.
BootType	Confidence interval type <code>bootci</code> uses to compute confidence bounds. You can specify any type supported by <code>bootci</code> . By default set to <code>'bca'</code> .
BootArg	Optional input arguments for <code>bootci</code> used to compute confidence bounds. You can specify all arguments <code>bootci</code> supports. Empty by default.

Output Arguments

- X *x*-coordinates for the performance curve. By default, X is false positive rate, FPR, (equivalently, fallout, or 1-specificity). To change this output, use the `'xCrit'` name/value input. For accepted criterion, see `'xCrit'` in “Input Arguments” on page 20-1709 for more information.

- Y *y*-coordinates for the performance curve. By default, Y is true positive rate, TPR, (equivalently, recall, or sensitivity). To change this output, use the `'yCrit'` input. For accepted criterion, see `'xCrit'` in “Input Arguments” on page 20-1709 for more information.

- T** An array of thresholds on classifier scores for the computed values of X and Y. It has the same number of rows as X and Y. For each threshold, TP is the count of true positive observations with scores greater or equal to this threshold, and FP is the count of false positive observations with scores greater or equal to this threshold. `perfcurve` defines negative counts, TN and FN, in a similar way then sorts the thresholds in the descending order which corresponds to the ascending order of positive counts.
- For the M distinct thresholds found in the array of scores, `perfcurve` returns the X, Y and T arrays with M+1 rows. `perfcurve` sets elements T(2:M+1) to the distinct thresholds, and T(1) replicates T(2). By convention, T(1) represents the highest 'reject all' threshold and `perfcurve` computes the corresponding values of X and Y for TP=0 and FP=0. T(end) is the lowest 'accept all' threshold for which TN=0 and FN=0.
- AUC** The area under curve (AUC) for the computed values of X and Y. If you set `xVals` to 'all' (the default), `perfcurve` computes AUC using the returned X and Y values. If `xVals` is a numeric array, `perfcurve` computes AUC using X and Y values found from all distinct scores in the interval specified by the smallest and largest elements of `xVals`. More precisely, `perfcurve` finds X values for all distinct thresholds as if `xVals` were set to 'all', then uses a subset of these (with corresponding Y values) between `min(xVals)` and `max(xVals)` to compute AUC. The function uses trapezoidal approximation to estimate the area. If the first or last value of X or Y are NaNs, `perfcurve` removes them to allow calculation of AUC. This takes care of criteria that produce NaNs for the special 'reject all' or 'accept all' thresholds, for example, positive predictive value (PPV) or negative predictive value (NPV).

OPTROCPPT The optimal operating point of the ROC curve as an array of size 1-by-2 with FPR and TPR values for the optimal ROC operating point. `perfcurve` computes `optrocppt` only for the standard ROC curve and sets to NaNs otherwise. To obtain the optimal operating point for the ROC curve, `perfcurve` first finds the slope, S , using

$$S = \frac{\text{cost}(P|N) - \text{cost}(N|N) * \frac{N}{P}}{\text{cost}(N|P) - \text{cost}(P|P)}$$

where $\text{cost}(I|J)$ is the cost of assigning an instance of class J to class I , and $P=TP+FN$ and $N=TN+FP$ are the total instance counts in the positive and negative class, respectively. `perfcurve` then finds the optimal operating point by moving the straight line with slope S from the upper left corner of the ROC plot (FPR=0, TPR=1) down and to the right until it intersects the ROC curve.

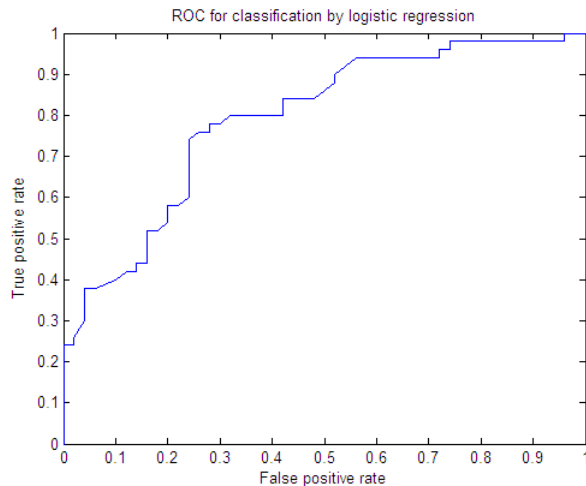
SUBY An array of Y values for negative subclasses. If you only specify one negative class, `SUBY` is identical to Y . Otherwise `SUBY` is a matrix of size M -by- K , where M is the number of returned values for X and Y , and K is the number of negative classes. `perfcurve` computes Y values by summing counts over all negative classes. `SUBY` gives values of the Y criterion for each negative class separately. For each negative class, `perfcurve` places a new column in `SUBY` and fills it with Y values for TN and FP counted just for this class.

SUBYNAMES A cell array of negative class names. If you provide an input array, `negClass`, of negative class names, `perfcurve` copies it into `SUBYNAMES`. If you do not provide `negClass`, `perfcurve` extracts `SUBYNAMES` from input labels. The order of `SUBYNAMES` is the same as the order of columns in `SUBY`, that is, `SUBY(:,1)` is for negative class `SUBYNAMES{1}` etc.

Examples

Plot the ROC curve for classification by logistic regression:

```
load fisheriris
x = meas(51:end,1:2);
% iris data, 2 classes and 2 features
y = (1:100) '>50';
% versicolor=0, virginica=1
b = glmfit(x,y,'binomial');
% logistic regression
p = glmval(b,x,'logit');
% fit probabilities for scores
[X,Y,T,AUC] = perfcurve(species(51:end,:),p,'virginica');
plot(X,Y)
xlabel('False positive rate'); ylabel('True positive rate')
title('ROC for classification by logistic regression')
```



Obtain errors on TPR by vertical averaging

```
[X,Y] = perfcurve(species(51:end,:),p,'virginica',...
    'nboot',1000,'xvals','all');
% plot errors
```

```
errorbar(X,Y(:,1),Y(:,2)-Y(:,1),Y(:,3)-Y(:,1));
```

References

- [1] T. Fawcett, ROC Graphs: Notes and Practical Considerations for Researchers, 2004.
- [2] M. Zweig and G. Campbell, Receiver-Operating Characteristic (ROC) Plots: A Fundamental Evaluation Tool in Clinical Medicine, *Clin. Chem.* 39/4, 561-577, 1993.
- [3] J. Davis and M. Goadrich, The relationship between precision-recall and ROC curves, in Proceedings of ICML '06, 233-240, 2006.
- [4] C. Moskowitz and M. Pepe, Quantifying and comparing the predictive accuracy of continuous prognostic factors for binary outcomes, *Biostatistics* 5, 113-127, 2004.
- [5] Y. Huang, M. Pepe and Z. Feng, Evaluating the Predictiveness of a Continuous Marker, U. Washington Biostatistics Paper Series, 282, 2006.
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- [7] http://www2.cs.uregina.ca/~hamilton/courses/831/notes/lift_chart/lift_chart.htm
<http://www.dmreview.com/news/5329-1.html>.
- [8] R. Bettinger, Cost-Sensitive Classifier Selection Using the ROC Convex Hull Method, SAS Institute.
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See Also

`bootci` | `glmfit` | `mnrfit` | `classify` | `NaiveBayes` | `classregtree`

How To

- “Grouping Variables” on page 2-72
- “Performance Curves” on page 12-39
- “Plotting a Classification Performance Curve” on page 13-138

perms

Purpose Enumeration of permutations

Syntax `P = perms(v)`

Description `P = perms(v)`, where `v` is a row vector of length `n`, creates a matrix whose rows consist of all possible permutations of the `n` elements of `v`. The matrix `P` contains `n!` rows and `n` columns.

`perms` is only practical when `n` is less than about 11 (for `n = 11`, the output takes over 3 gigabytes).

Examples `perms([2 4 6])`

`ans =`

```
6 4 2
6 2 4
4 6 2
4 2 6
2 4 6
2 6 4
```

See Also

`combnk`

Purpose Permute dimensions of categorical array

Syntax `B = permute(A,order)`

Description `B = permute(A,order)` rearranges the dimensions of the categorical array `A` so that they are in the order specified by the vector `order`. The array produced has the same values as `A` but the order of the subscripts needed to access any particular element are rearranged as specified by `order`. The elements of `order` must be a rearrangement of the numbers from 1 to `n`.

See Also `circshift` | `ipermute`

piecewisedistribution

Purpose Piecewise-defined distributions

Construction `piecewisedistribution` is an abstract class. To construct a `piecewisedistribution` object, use the subclass constructor, `paretotails`.

Methods	<code>boundary</code>	Piecewise distribution boundaries
	<code>cdf</code>	Cumulative distribution function for piecewise distribution
	<code>disp</code>	Display <code>piecewisedistribution</code> object
	<code>display</code>	Display <code>piecewisedistribution</code> object
	<code>icdf</code>	Inverse cumulative distribution function for piecewise distribution
	<code>nsegments</code>	Number of segments
	<code>pdf</code>	Probability density function for piecewise distribution
	<code>random</code>	Random numbers from piecewise distribution
	<code>segment</code>	Segments containing values

Properties Objects of the `piecewisedistribution` class have no properties accessible by dot indexing, `get` methods, or `set` methods. To obtain information about a `piecewisedistribution` object, use the appropriate method.

Copy Semantics Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

Purpose Create piecewise distribution object

Description `piecewisedistribution` is an abstract class, and you cannot create instances of it directly. You can create `paretotails` objects that are derived from this class.

See Also `paretotails`

LinearModel.plot

Purpose Scatter plot or added variable plot of linear model

Syntax `plot mdl)`
`h = plot(mdl)`

Description `plot(mdl)` creates a plot of the fitted linear model. The plot type depends on the number of predictor variables.

- If there is just one predictor variable, `plot` creates a scatter plot of the data along with a fitted curve and confidence bounds.
- If there are multiple predictor variables, `plot` creates an added variable plot.
- If there are no predictors, `plot` creates a histogram of the residuals.

`h = plot(mdl)` returns handles to the lines in the plot.

Input Arguments **mdl**
Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

Output Arguments **h**
Vector of handles to lines or patches in the plot.

Definitions **Added Variable Plot, Adjusted Response**

An added variable plot illustrates the incremental effect on the response of specified terms by removing the effects of all other terms. The slope of the fitted line is the coefficient of the linear combination of the specified terms projected onto the best-fitting direction. The adjusted response includes the constant (intercept) terms, and averages out all other terms.

Examples

Create an Added Variable Plot

Create a model of car mileage as a function of weight and model year. Then create a plot to see the significance of the model.

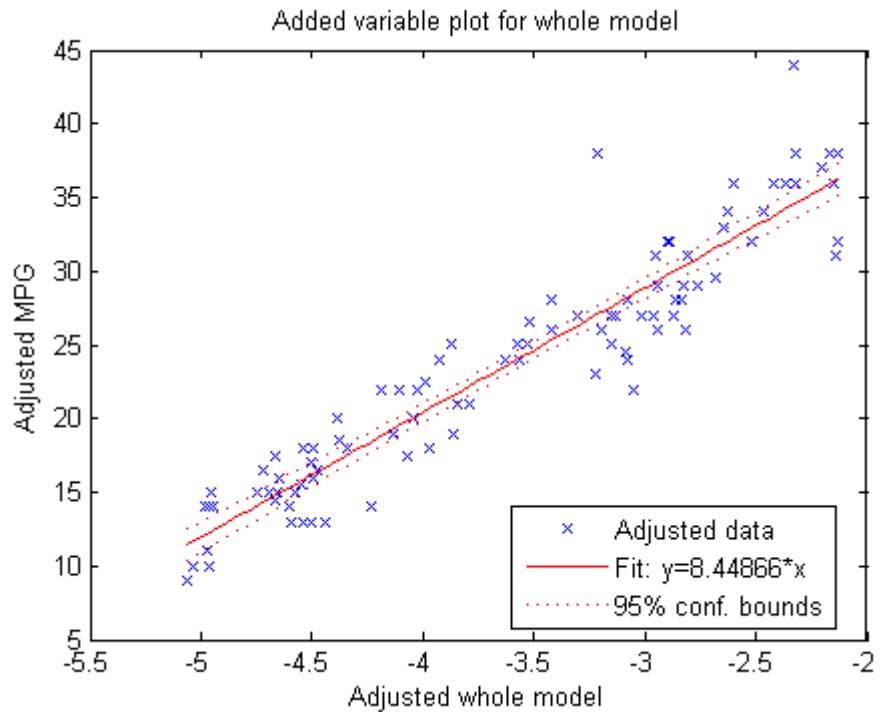
Create a linear model of mileage from the `carsmall` data.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Create an added variable plot.

```
plot(mdl)
```

LinearModel.plot



The plot illustrates that the model is significant—a horizontal line does not fit between the confidence bounds.

Alternatives

Use `plotAdded` to select particular predictors for an added variable plot.

See Also

`LinearModel` | `plotAdded`

How To

- “Linear Regression” on page 9-7

Purpose

Added variable plot or leverage plot for linear model

Syntax

```
plotAdded mdl
plotAdded mdl,coef
h = plotAdded mdl,...
h = plotAdded mdl,coef,Name,Value
```

Description

`plotAdded(mdl)` produces a generalized added variable plot for all terms in `mdl` except the constant term.

`plotAdded(mdl,coef)` produces an added variable plot for the `coef` terms in `mdl`, after adjusting for all other terms.

`h = plotAdded(mdl,...)` returns handles to the lines in the plot.

`h = plotAdded(mdl,coef,Name,Value)` plots with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the *x* and *y* values for any data point, along with the observation name or number.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

coef

Coefficients in `mdl`. Represent as:

- String giving a single coefficient name
- Vector of coefficient numbers in the `mdl.CoefficientNames` property

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can

LinearModel.plotAdded

specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerFaceColor

Color of the marker face for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerSize

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

Output Arguments

h

Vector of handles to lines or patches in the plot.

Definitions

Added Variable Plot, Adjusted Response

An added variable plot illustrates the incremental effect on the response of specified terms by removing the effects of all other terms. The slope of the fitted line is the coefficient of the linear combination of the specified terms projected onto the best-fitting direction. The adjusted response includes the constant (intercept) terms, and averages out all other terms.

Examples

Create an Added Variable Plot

Create a model of car mileage as a function of weight and model year. Then create a plot to see the significance of the model.

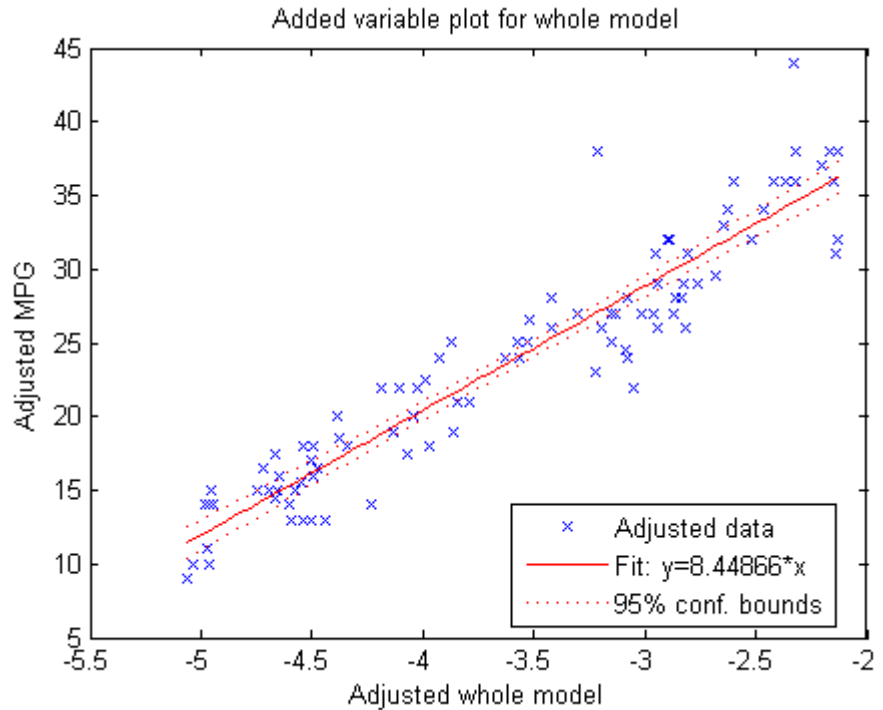
Create a linear model of mileage from the carsmall data.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Create an added variable plot.

```
plotAdded(mdl)
```

LinearModel.plotAdded



The plot illustrates that the model is significant—a horizontal line does not fit between the confidence bounds.

Create an Added Variable Plot for Particular Variables

Create a model of car mileage as a function of weight and model year. Then create a plot to see the effect of the weight terms (Weight and Weight²).

Create a linear model of mileage from the carsmall data.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Find the terms in the model corresponding to the Weight and Weight².

```
mdl.CoefficientNames
```

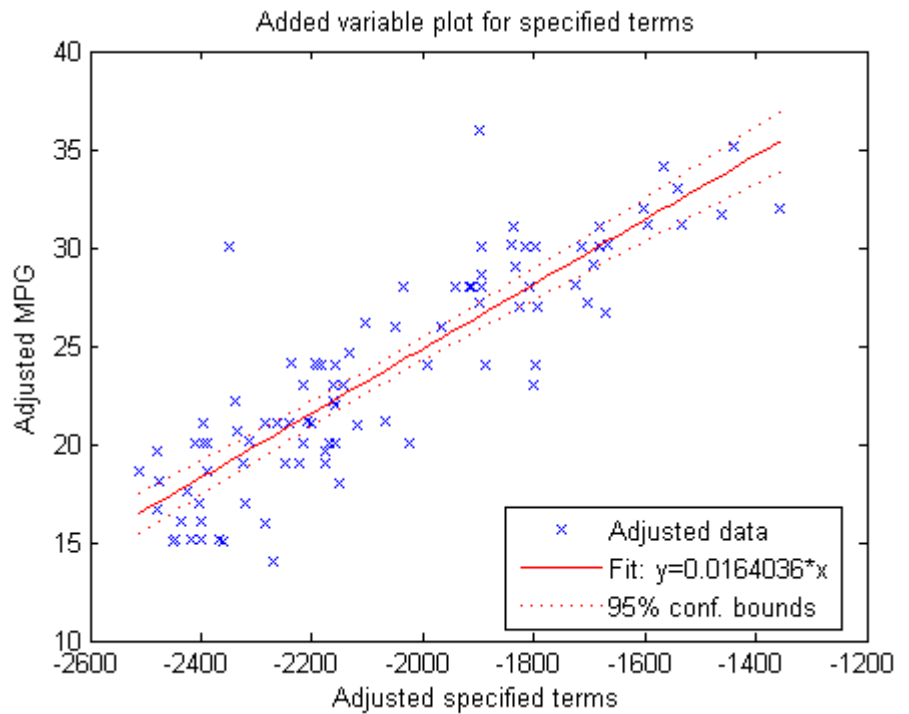
```
ans =
```

```
'(Intercept)' 'Weight' 'Year_76' 'Year_82' 'Weight^2'
```

The weight terms are 2 and 5.

Create an added variable plot with the weight terms.

```
coef = [2 5];  
plotAdded(mdl,coef)
```



LinearModel.plotAdded

The plot illustrates that the weight terms are significant—a horizontal line does not fit between the confidence bounds.

See Also

`LinearModel | plot`

Tutorials

- “Plots to Understand Terms Effects” on page 9-31

How To

- “Linear Regression” on page 9-7

LinearModel.plotAdjustedResponse

Purpose

Adjusted response plot for linear regression model

Syntax

```
plotAdjustedResponse mdl, var)
h = plotAdjustedResponse mdl, var)
h = plotAdjustedResponse mdl, var, Name, Value)
```

Description

`plotAdjustedResponse mdl, var)` gives an adjusted response plot for the variable `var` in the `mdl` regression model.

`h = plotAdjustedResponse mdl, var)` returns handles to the lines in the plot.

`h = plotAdjustedResponse mdl, var, Name, Value)` plots with additional options specified by one or more `Name, Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the x and y values for any data point, along with the observation name or number.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

var

Variable name, or scalar index of variable in `mdl.CoefficientNames`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

LinearModel.plotAdjustedResponse

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerFaceColor

Color of the marker face for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerSize

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

Output Arguments

h

Vector of handles to lines or patches in the plot.

Definitions

Adjusted Response Plot

The adjusted response plot shows the fitted response as a function of var, with the other predictors averaged out by averaging the fitted values over the data used in the fit. Adjusted data points are computed by adding the residual to the adjusted fitted value for each observation.

Examples

Plot Adjusted Responses

Plot the adjusted responses of a fitted linear model.

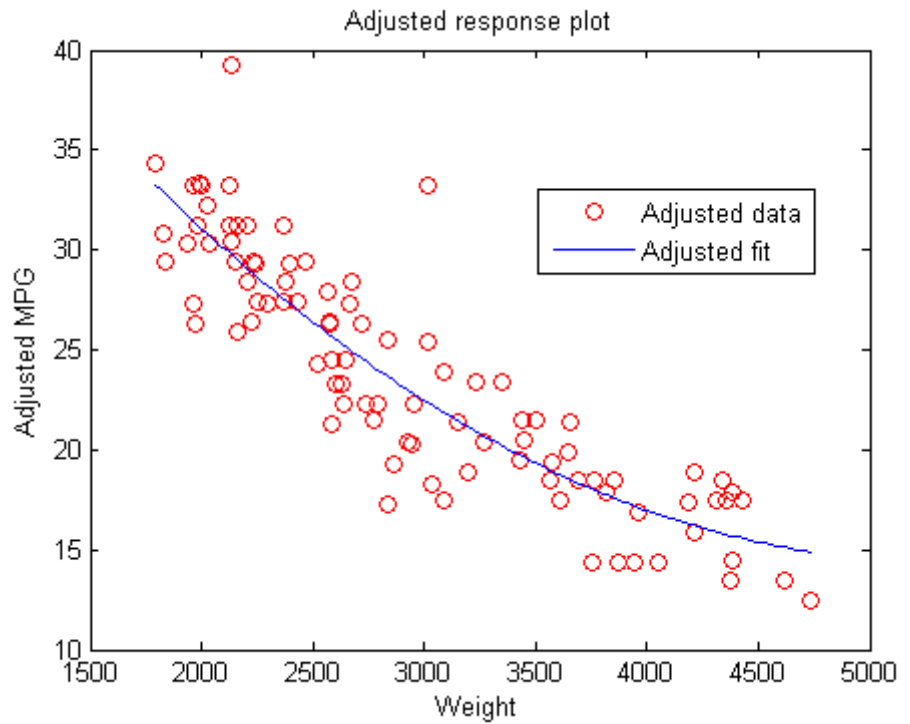
Load the `carsmall` data and fit a linear model of the mileage as a function of model year, weight, and weight squared.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Plot the effect of 'Weight' averaged over Year values.

```
plotAdjustedResponse(mdl,'Weight')
```

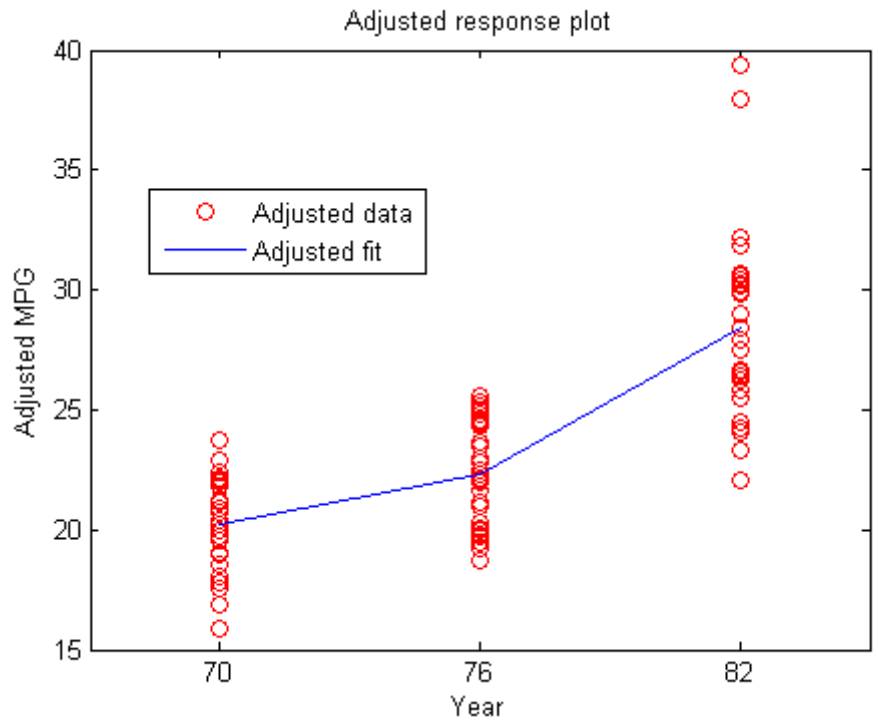
LinearModel.plotAdjustedResponse



Plot the effect of Year averaged over 'Weight' values. Include the h output.

```
h = plotAdjustedResponse mdl, 'Year' );
```

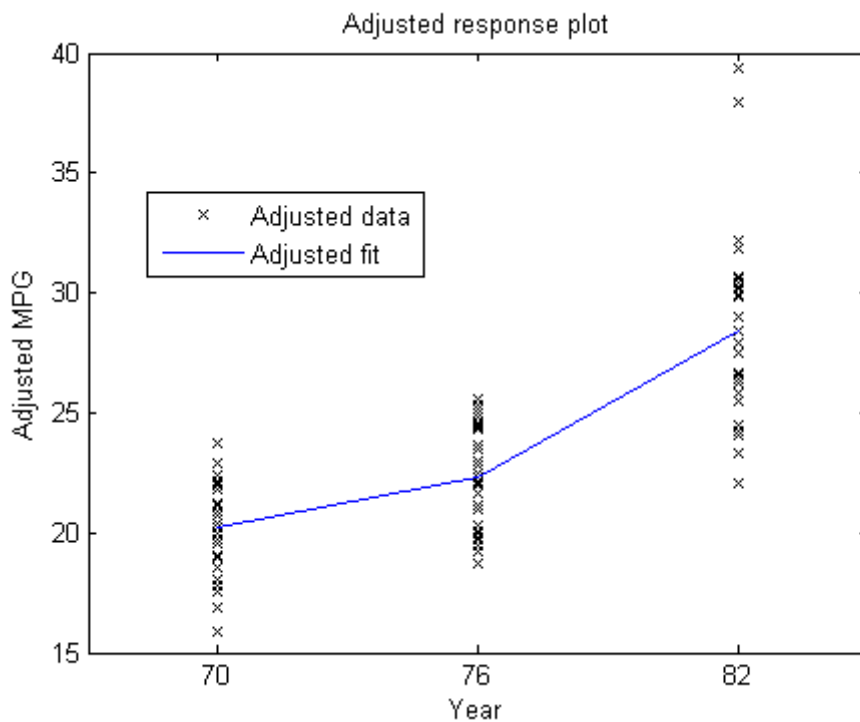

LinearModel.plotAdjustedResponse



Change the adjusted data to black x instead of red o.

```
set(h(1), 'Marker', 'x', 'Color', 'k')
```

LinearModel.plotAdjustedResponse



See Also

[LinearModel](#) | [plotAdded](#) | [plotEffects](#) | [plotInteraction](#)

How To

- “Linear Regression” on page 9-7

GeneralizedLinearModel.plotDiagnostics

Purpose Plot diagnostics of generalized linear regression model

Syntax

```
plotDiagnostics mdl
plotDiagnostics mdl,plottype
h = plotDiagnostics(...)
h = plotDiagnostics mdl,plottype,Name,Value
```

Description

`plotDiagnostics(mdl)` plots diagnostics from the `mdl` linear model using leverage as the plot type.

`plotDiagnostics(mdl,plottype)` plots diagnostics from the `mdl` generalized linear model in a plot of type `plottype`.

`h = plotDiagnostics(...)` returns handles to the lines in the plot.

`h = plotDiagnostics(mdl,plottype,Name,Value)` plots with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the x and y values for any data point, along with the observation name or number.

Input Arguments

mdl

Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

plottype

String specifying the type of plot:

'contour'	Residual vs. leverage with overlaid Cook's contours
'cookd'	Cook's distance
'leverage'	Leverage (diagonal of Hat matrix)

GeneralizedLinearModel.plotDiagnostics

Default: 'leverage'

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerFaceColor

Color of the marker face for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerSize

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

Output Arguments

h

Vector of handles to lines or patches in the plot.

Definitions

Hat Matrix

The *hat matrix* H is defined in terms of the data matrix X and a diagonal weight matrix W :

$$H = X(X^T W X)^{-1} X^T W^T.$$

W has diagonal elements w_i :

$$w_i = \frac{g'(\mu_i)}{\sqrt{V(\mu_i)}},$$

where

- g is the link function mapping y_i to $x_i b$.
- g' is the derivative of the link function g .
- V is the variance function.
- μ_i is the i th mean.

The diagonal elements H_{ii} satisfy

$$0 \leq h_{ii} \leq 1$$

$$\sum_{i=1}^n h_{ii} = p,$$

GeneralizedLinearModel.plotDiagnostics

where n is the number of observations (rows of X), and p is the number of coefficients in the regression model.

Leverage

The *leverage* of observation i is the value of the i th diagonal term of the hat matrix H_{ii} . Because the sum of the leverage values is p (the number of coefficients in the regression model), an observation i can be considered to be an outlier if its leverage substantially exceeds p/n , where n is the number of observations.

Cook's Distance

The Cook's distance D_i of observation i is

$$D_i = w_i \frac{e_i^2}{p\hat{\phi}} \frac{h_{ii}}{(1-h_{ii})^2},$$

where

- $\hat{\phi}$ is the dispersion parameter (estimated or theoretical).
- e_i is the linear predictor residual, $g(y_i) - x_i\hat{\beta}$, where
 - g is the link function.
 - y_i is the observed response.
 - x_i is the observation.
 - $\hat{\beta}$ is the estimated coefficient vector.
- p is the number of coefficients in the regression model.
- h_{ii} is the i th diagonal element of the Hat Matrix H .

Examples

Diagnostic Plots for Generalized Linear Models

Create leverage and Cook's distance plots of a fitted generalized linear model.

GeneralizedLinearModel.plotDiagnostics

Generate artificial data for the model, Poisson random numbers with two underlying predictors $X(1)$ and $X(2)$.

```
rng('default') % for reproducibility
rndvars = randn(100,2);
X = [2+rndvars(:,1),rndvars(:,2)];
mu = exp(1 + X*[1;2]);
y = poissrnd(mu);
```

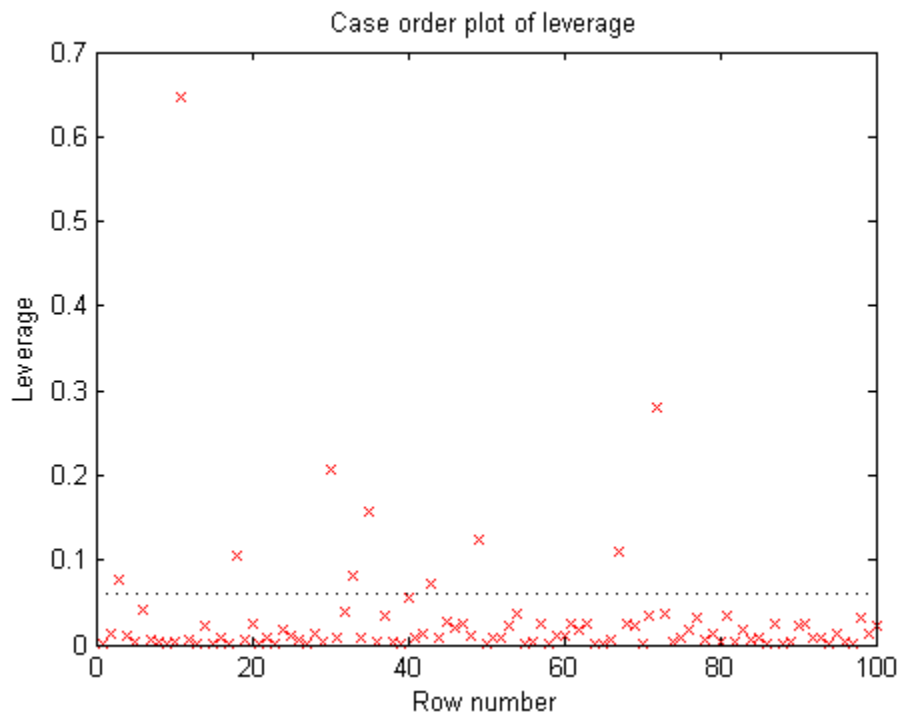
Create a generalized linear regression model of Poisson data.

```
mdl = GeneralizedLinearModel.fit(X,y,...
    'y ~ x1 + x2','distr','poisson');
```

Create a leverage plot.

```
plotDiagnostics(mdl)
```

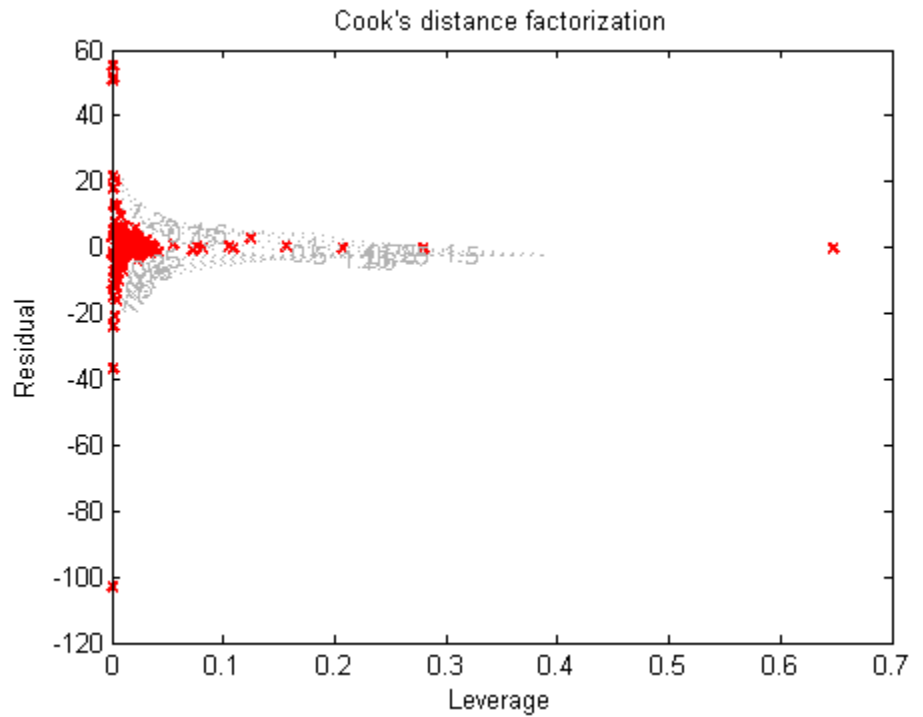
GeneralizedLinearModel.plotDiagnostics



Create a contour plot with Cook's distance.

```
plotDiagnostics mdl, 'contour'
```


GeneralizedLinearModel.plotDiagnostics



References

[1] Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. *Applied Linear Statistical Models*, Fourth Edition. Irwin, Chicago, 1996.

See Also `GeneralizedLinearModel |`

Related Examples

- “Diagnostic Plots” on page 9-155

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.plotDiagnostics

Purpose Plot diagnostics of linear regression model

Syntax

```
plotDiagnostics mdl
plotDiagnostics mdl,plottype
h = plotDiagnostics(...)
h = plotDiagnostics mdl,plottype,Name,Value
```

Description

`plotDiagnostics mdl` plots diagnostics from the `mdl` linear model using scaled delete-1 fitted values.

`plotDiagnostics mdl,plottype` plots diagnostics in a plot of type `plottype`.

`h = plotDiagnostics(...)` returns handles to the lines in the plot.

`h = plotDiagnostics mdl,plottype,Name,Value` plots with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the x and y values for any data point, along with the observation name or number.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

plottype

String specifying the type of plot:

'contour'	Residual vs. leverage with overlaid Cook's contours
'cookd'	Cook's distance
'covratio'	Delete-1 ratio of determinant of covariance

'dfbetas'	Scaled delete-1 coefficient estimates
'dffits'	Scaled delete-1 fitted values
'leverage'	Leverage
's2_i'	Delete-1 variance estimate

Delete-1 means compute a new model without the current observation. If the delete-1 calculation differs significantly from the model using all observations, then the observation is influential.

Default: 'leverage'

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

LinearModel.plotDiagnostics

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or ColorSpec specification. For details, see linespec.

MarkerFaceColor

Color of the marker face for filled markers, a string or ColorSpec specification. For details, see linespec.

MarkerSize

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

Output Arguments

h

Vector of handles to lines or patches in the plot.

Definitions

Hat Matrix

The *hat matrix* H is defined in terms of the data matrix X :

$$H = X(X^T X)^{-1} X^T.$$

The diagonal elements H_{ii} satisfy

$$0 \leq h_{ii} \leq 1$$

$$\sum_{i=1}^n h_{ii} = p,$$

where n is the number of observations (rows of X), and p is the number of coefficients in the regression model.

Leverage

The *leverage* of observation i is the value of the i th diagonal term of the hat matrix H_{ii} . Because the sum of the leverage values is p (the

number of coefficients in the regression model), an observation i can be considered to be an outlier if its leverage substantially exceeds p/n , where n is the number of observations.

Cook's Distance

Cook's distance is the scaled change in fitted values. Each element in `CooksDistance` is the normalized change in the vector of coefficients due to the deletion of an observation. The Cook's distance, D_i , of observation i is

$$D_i = \frac{\sum_{j=1}^n (\hat{y}_j - \hat{y}_{j(i)})^2}{p \text{MSE}},$$

where

- \hat{y}_j is the j th fitted response value.
- $\hat{y}_{j(i)}$ is the j th fitted response value, where the fit does not include observation i .
- MSE is the mean squared error.
- p is the number of coefficients in the regression model.

Cook's distance is algebraically equivalent to the following expression:

$$D_i = \frac{r_i^2}{p \text{MSE}} \left(\frac{h_{ii}}{(1 - h_{ii})^2} \right),$$

where r_i is the i th residual, and h_{ii} is the i th leverage value.

`CooksDistance` is an n -by-1 column vector in the `Diagnostics` dataset array of the `LinearModel` object.

LinearModel.plotDiagnostics

Examples

Leverage Plot of Linear Model

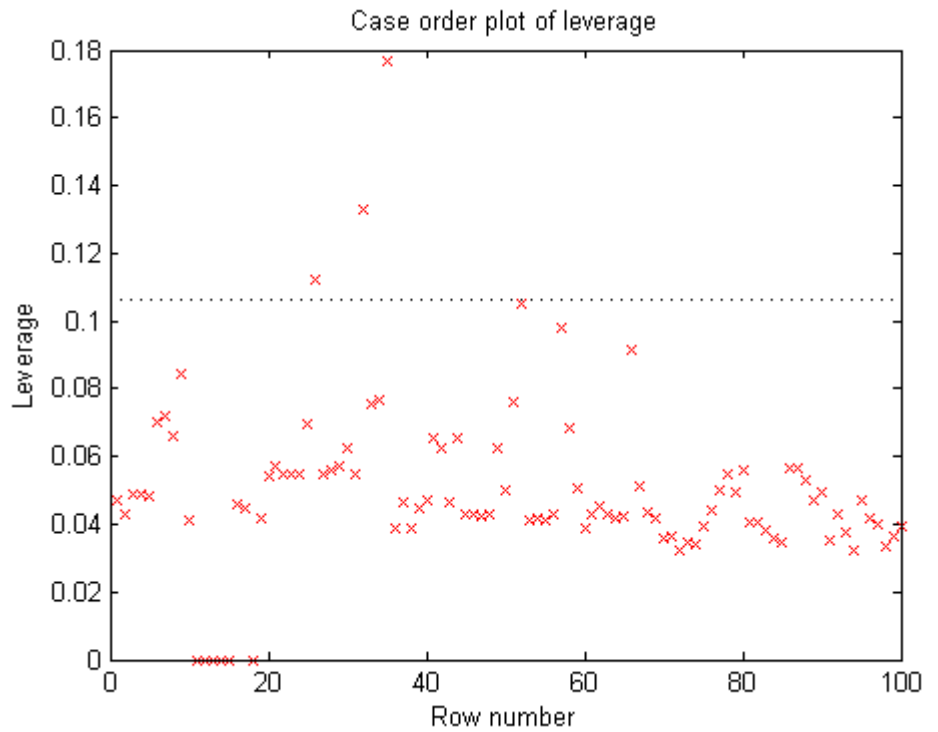
Plot the leverage values of observations in a fitted model.

Load the `carsmall` data and fit a linear model of the mileage as a function of model year, weight, and weight squared.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight^2');
```

Plot the leverage values.

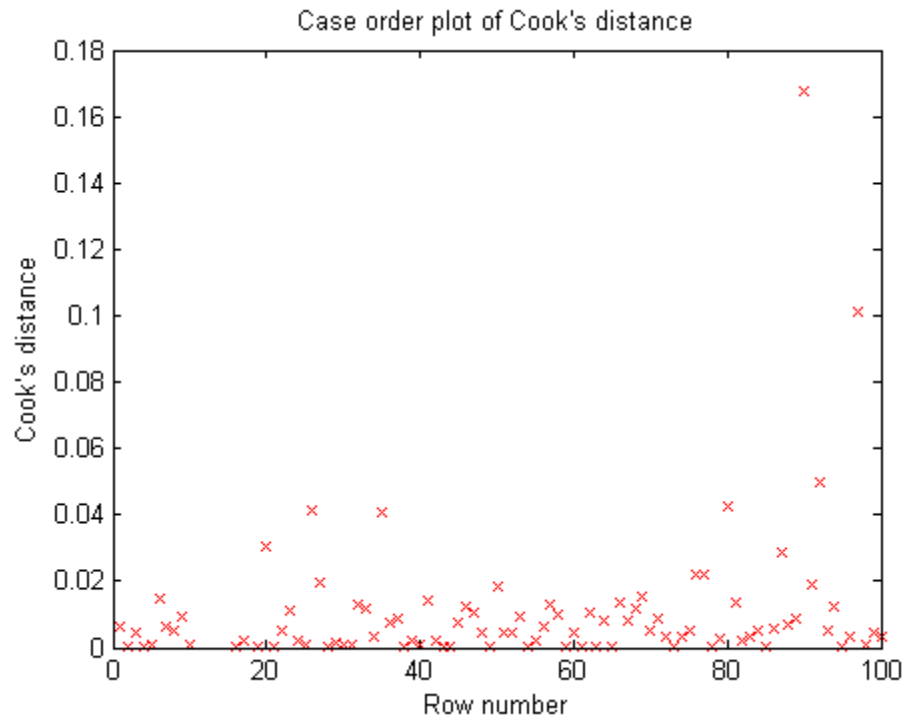
```
plotDiagnostics(mdl)
```



Plot the Cook's distance.

```
plotDiagnostics(md1, 'cookd')
```

LinearModel.plotDiagnostics



The two diagnostic plots give different results.

References

[1] Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. *Applied Linear Statistical Models*, Fourth Edition. Irwin, Chicago, 1996.

Alternatives

The `mdl.Diagnostics` property contains the information that `plotDiagnostics` uses to create plots.

See Also

`LinearModel`

Tutorials

- “Diagnostic Plots” on page 9-20

How To

- “Linear Regression” on page 9-7

NonLinearModel.plotDiagnostics

Purpose Plot diagnostics of nonlinear regression model

Syntax

```
plotDiagnostics mdl
plotDiagnostics mdl,plottype
h = plotDiagnostics(...)
h = plotDiagnostics mdl,plottype,Name,Value
```

Description

`plotDiagnostics(mdl)` plots diagnostics from the `mdl` linear model using leverage as the plot type.

`plotDiagnostics(mdl,plottype)` plots diagnostics in a plot of type `plottype`.

`h = plotDiagnostics(...)` returns handles to the lines in the plot.

`h = plotDiagnostics(mdl,plottype,Name,Value)` plots with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the *x* and *y* values for any data point, along with the observation name or number.

Input Arguments

mdl Nonlinear regression model, constructed by `NonLinearModel.fit`.

plottype

String specifying the type of plot:

'contour'	Residual vs. leverage with overlaid Cook's contours
'cookd'	Cook's distance
'leverage'	Leverage (diagonal of Hat matrix)

Default: 'leverage'

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerFaceColor

Color of the marker face for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerSize

NonLinearModel.plotDiagnostics

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

Output Arguments

h

Vector of handles to lines or patches in the plot.

Definitions

Hat Matrix

The *hat matrix* H is defined in terms of the data matrix X and the Jacobian matrix J :

$$J_{i,j} = \left. \frac{\partial f}{\partial \beta_j} \right|_{x_i, \beta}$$

Here f is the nonlinear model function, and β is the vector of model coefficients.

The Hat Matrix H is

$$H = J(J^T J)^{-1} J^T.$$

The diagonal elements H_{ii} satisfy

$$0 \leq h_{ii} \leq 1$$
$$\sum_{i=1}^n h_{ii} = p,$$

where n is the number of observations (rows of X), and p is the number of coefficients in the regression model.

Leverage

The *leverage* of observation i is the value of the i th diagonal term of the hat matrix H_{ii} . Because the sum of the leverage values is p (the number of coefficients in the regression model), an observation i can be considered to be an outlier if its leverage substantially exceeds p/n , where n is the number of observations.

Cook's Distance

The Cook's distance D_i of observation i is

$$D_i = \frac{\sum_{j=1}^n (\hat{y}_j - \hat{y}_{j(i)})^2}{p \text{MSE}},$$

where

- \hat{y}_j is the j th fitted response value.
- $\hat{y}_{j(i)}$ is the j th fitted response value, where the fit does not include observation i .
- MSE is the mean squared error.
- p is the number of coefficients in the regression model.

Cook's distance is algebraically equivalent to the following expression:

$$D_i = \frac{r_i^2}{p \text{MSE}} \left(\frac{h_{ii}}{(1 - h_{ii})^2} \right),$$

where e_i is the i th residual.

Examples

Nonlinear Model Leverage Plot

Create a leverage plot of a fitted nonlinear model, and find the points with high leverage.

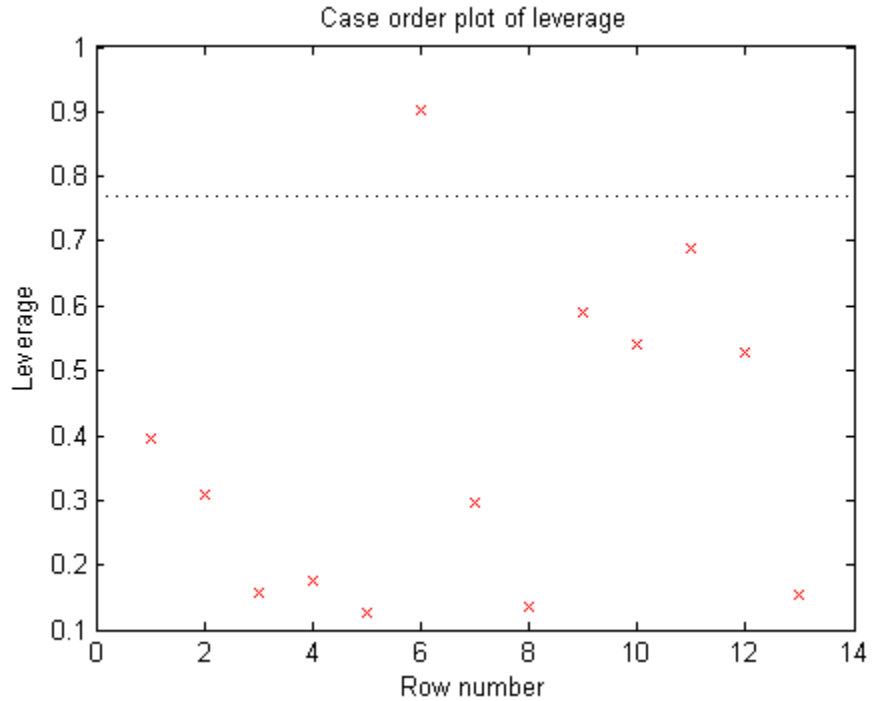
Load the reaction data and fit a model of the reaction rate as a function of reactants.

```
load reaction
mdl = NonLinearModel.fit(reactants,...
    rate,@hougen,[1 .05 .02 .1 2]);
```

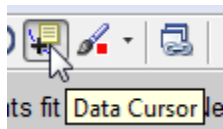
NonLinearModel.plotDiagnostics

Create a leverage plot of the fitted model.

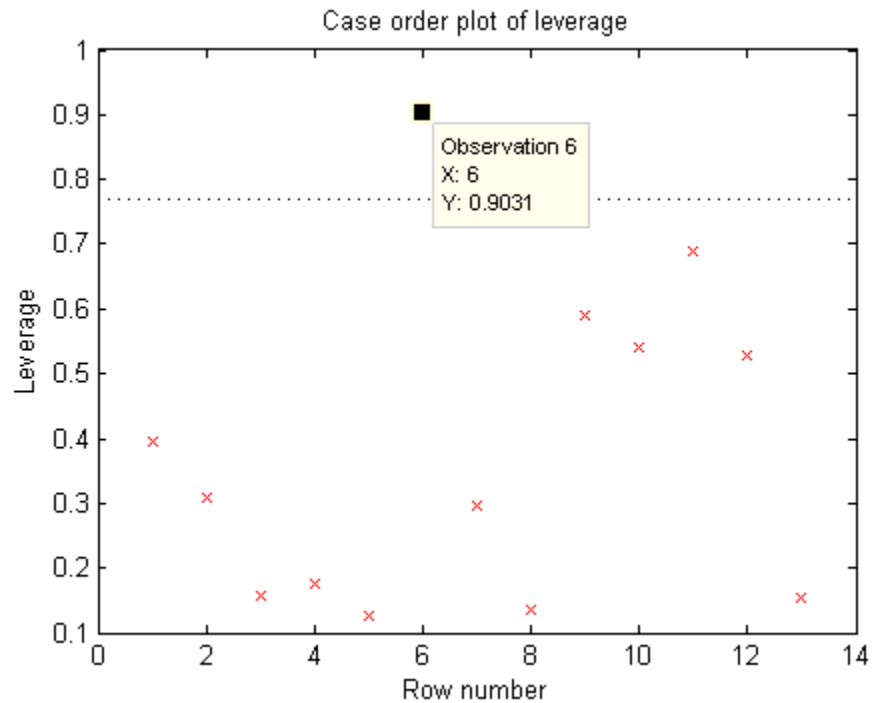
```
plotDiagnostics(md1)
```



To examine the observation with high leverage, activate the Data Cursor and click the observation.



NonLinearModel.plotDiagnostics



Alternatively, find the high-leverage observation at the command line.

```
find(md1.Diagnostics.Leverage > 0.8)
```

```
ans =
```

```
6
```

References

[1] Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. *Applied Linear Statistical Models*, Fourth Edition. Irwin, Chicago, 1996.

See Also

NonLinearModel | plotResiduals |

NonLinearModel.plotDiagnostics

Related Examples

- “Examine Quality and Adjust the Fitted Model” on page 9-202
- “Nonlinear Regression Workflow” on page 9-210

Concepts

- “Nonlinear Regression” on page 9-196

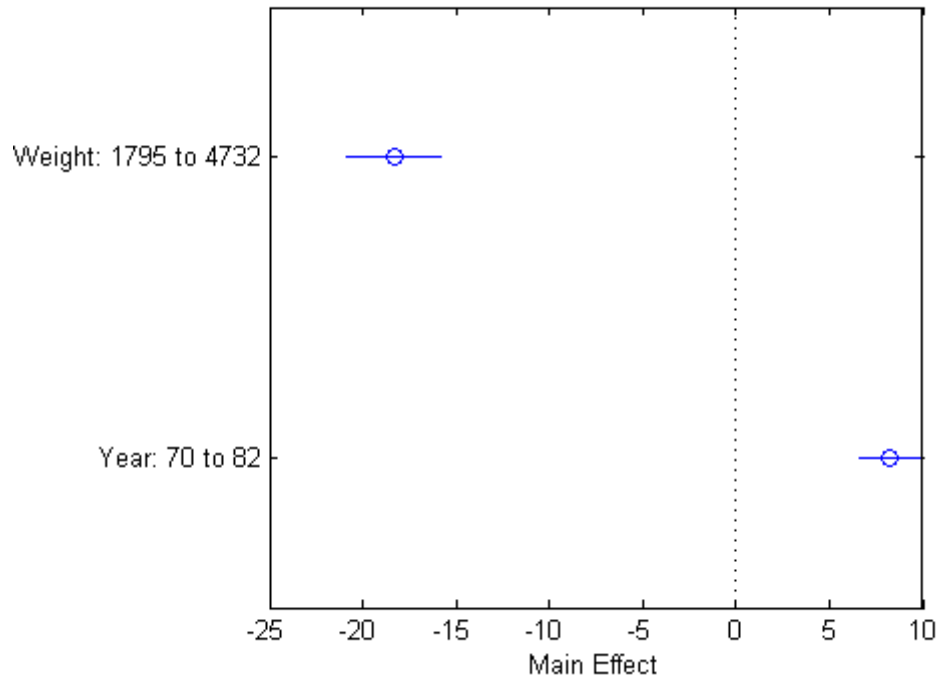
Purpose	Plot main effects of each predictor in linear regression model
Syntax	<pre>plotEffects mdl h = plotEffects mdl</pre>
Description	<p><code>plotEffects(mdl)</code> produces an effects plot for the predictors in the <code>mdl</code> regression model. The plot shows the estimated effect on the response from changing each predictor value, averaging out the effects of the other predictors. <code>plotEffects</code> chooses values to produce a relatively large effect on the response.</p> <p><code>h = plotEffects(mdl)</code> returns handles to the lines in the plot.</p>
Tips	<ul style="list-style-type: none">• For many plots, the Data Cursor tool in the figure window displays the x and y values for any data point, along with the observation name or number.
Input Arguments	<p>mdl</p> <p>Linear model, as constructed by <code>LinearModel.fit</code> or <code>LinearModel.stepwise</code>.</p>
Output Arguments	<p>h</p> <p>Vector of handles to lines or patches in plot. <code>h(1)</code> is a handle to the circles that represent the main effect estimates. <code>h(j+1)</code> is a handle to the line that defines the confidence interval for the effect of predictor j.</p>
Examples	<p>Effects Plot</p> <p>Plot the effects of two predictors in a fitted linear model.</p> <p>Load the <code>carsmall</code> data and fit a linear model of the mileage as a function of model year, weight, and weight squared.</p> <pre>load carsmall ds = dataset(MPG,Weight);</pre>

LinearModel.plotEffects

```
ds.Year = ordinal(Model_Year);  
mdl = LinearModel.fit(ds, 'MPG ~ Year + Weight^2');
```

Create an effects plot.

```
plotEffects(mdl)
```



The width of each horizontal line in the figure shows a confidence interval for the effect on the response of the listed change in each predictor. The estimated effect of changing Year from 70 to 82 is an increase of about 8, and is between 6 and 10 with 95% confidence.

Alternatives

Use `plotInteraction` for an effects plot of the interactions of two specified variables.

See Also

[LinearModel](#) | [plotAdjustedResponse](#) | [plotInteraction](#)

Tutorials

- “Plots to Understand Predictor Effects” on page 9-26

How To

- “Linear Regression” on page 9-7

LinearModel.plotInteraction

Purpose Plot interaction effects of two predictors in linear regression model

Syntax

```
plotInteraction mdl, var1, var2)
plotInteraction mdl, var1, var2, ptype)
h = plotInteraction(...)
```

Description `plotInteraction mdl, var1, var2)` creates a plot of the interaction effects of the predictors `var1` and `var2` in `mdl`. The plot shows the estimated effect on the response from changing each predictor value, averaging out the effects of the other predictors. The plot also shows the estimated effect with the other predictor fixed at certain values. `plotInteraction` chooses values to produce a relatively large effect on the response. The plot lets you examine whether the effect of one predictor depends on the value of the other predictor.

`plotInteraction mdl, var1, var2, ptype)` returns a plot of the type specified in `ptype`.

`h = plotInteraction(...)` returns handles to the lines in the plot.

Tips

- For many plots, the Data Cursor tool in the figure window displays the *x* and *y* values for any data point, along with the observation name or number.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

var1

String naming the variable for plot. `plotInteraction` chooses values of `var1` to create relatively large changes in the response. When you set `ptype = 'predictions'`, the plot shows curves as a function of `var2` with various fixed values of `var1`.

var2

String naming the variable for plot. `plotInteraction` chooses values of `var2` to create relatively large changes in the response.

When you set `pctype = 'predictions'`, the plot shows curves as a function of `var2` various fixed values of `var1`.

pctype

String naming the plot type.

- `'effects'` — The plot shows each effect as a circle, with a horizontal bar showing the confidence interval for the estimated effect. `plotInteraction` computes the effect values from the adjusted response curve, as shown by the `plotAdjustedResponse` function.
- `'predictions'` — The plot shows the adjusted response curve as a function of `var2`, with `var1` fixed at certain values.

Default: `'effects'`

Output Arguments

h

Vector of handles to lines or patches in the plot.

Examples

Interaction Plot

Create a model of car mileage as a function of weight and model year. Then create a plot to see if the predictors have interactions.

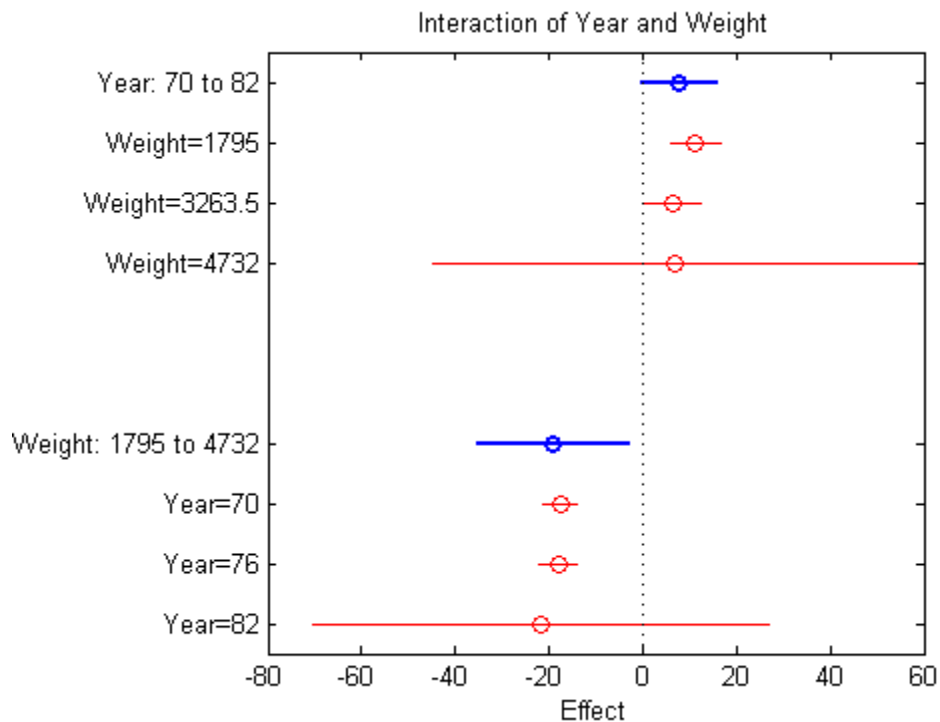
Create a linear model of mileage from the `carsmall` data.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
var1 = 'Year';
var2 = 'Weight';
mdl = LinearModel.fit(ds,'MPG ~ Year * Weight^2');
```

Create an interaction plot.

```
plotInteraction(mdl,var1,var2)
```

LinearModel.plotInteraction



The plot might show an interaction, because the groups of points are not perfectly vertical. But the error bars seem large enough that a vertical line could pass within all of the confidence intervals for each group, possibly indicating no interaction.

Prediction Curve Interaction Plot

Create a model of car mileage as a function of weight and model year. Then create an interaction curve plot to see if the predictors have interactions.

Create a linear model of mileage from the carsmall data.

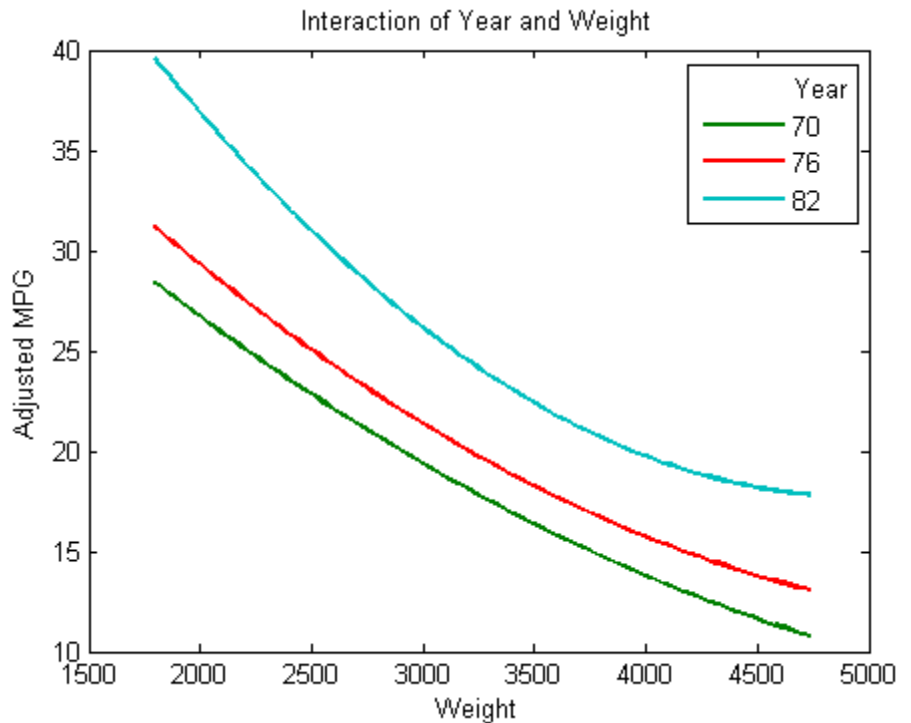
```
load carsmall
```

LinearModel.plotInteraction

```
ds = dataset(MPG,Weight);  
ds.Year = ordinal(Model_Year);  
var1 = 'Year';  
var2 = 'Weight';  
mdl = LinearModel.fit(ds,'MPG ~ Year * Weight^2');
```

Create an interaction plot with type 'predictions'.

```
plotInteraction(mdl,var1,var2,'predictions')
```



The curves are not parallel. This indicates interactions between the predictors. The effect is subtle enough not to definitively indicate a interaction.

LinearModel.plotInteraction

Alternatives Use `plotEffects` for an effects plot showing separate effects for all predictors.

See Also `LinearModel` | `plotAdjustedResponse` | `plotEffects`

Tutorials • “Plots to Understand Predictor Effects” on page 9-26

How To • “Linear Regression” on page 9-7

GeneralizedLinearModel.plotResiduals

Purpose

Plot residuals of generalized linear regression model

Syntax

```
plotResiduals mdl
plotResiduals mdl, plottype
h = plotResiduals(...)
h = plotResiduals(mdl, plottype, Name, Value)
```

Description

`plotResiduals(mdl)` gives a histogram plot of the residuals of the `mdl` nonlinear model.

`plotResiduals(mdl, plottype)` plots residuals in a plot of type `plottype`.

`h = plotResiduals(...)` returns handles to the lines in the plot.

`h = plotResiduals(mdl, plottype, Name, Value)` plots with additional options specified by one or more `Name, Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the x and y values for any data point, along with the observation name or number.

Input Arguments

mdl

Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

plottype

String specifying the type of plot:

'caseorder'	Residuals vs. case (row) order
'fitted'	Residuals vs. fitted values
'histogram'	Histogram
'lagged'	Residuals vs. lagged residual ($r(t)$ vs. $r(t-1)$)

GeneralizedLinearModel.plotResiduals

'probability'	Normal probability plot
'symmetry'	Symmetry plot

Default: 'histogram'

Name-Value Pair Arguments

Specify optional comma-separated pairs of **Name**, **Value** arguments, where **Name** is the argument name and **Value** is the corresponding value. **Name** must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as **Name1**, **Value1**, ..., **NameN**, **ValueN**.

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

GeneralizedLinearModel.plotResiduals

MarkerFaceColor

Color of the marker face for filled markers, a string or ColorSpec specification. For details, see `linespec`.

MarkerSize

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

ResidualType

String giving type of residual used in the plot.

'Raw'	Observed minus fitted values
'LinearPredictor'	Residuals on the linear predictor scale, equal to the adjusted response value minus the fitted linear combination of the predictors
'Pearson'	Raw residuals divided by RMSE
'Anscombe'	Residuals defined on transformed data with the transformation chosen to remove skewness
'Deviance'	Residuals based on the contribution of each observation to the deviance

Default: 'Raw'

Output Arguments

h

Vector of handles to lines or patches in the plot.

Definitions

Deviance

Deviance is twice the log likelihood of the model. Because this overall log likelihood is a sum of log likelihoods for each observation, the residual plot of deviance type shows the log likelihood per observation.

GeneralizedLinearModel.plotResiduals

Examples

Residual Plots for Generalized Linear Models

Create residual plots of a fitted generalized linear model.

Generate artificial data for the model, Poisson random numbers with two underlying predictors $X(1)$ and $X(2)$.

```
rng('default') % for reproducibility
rndvars = randn(100,2);
X = [2+rndvars(:,1),rndvars(:,2)];
mu = exp(1 + X*[1;2]);
y = poissrnd(mu);
```

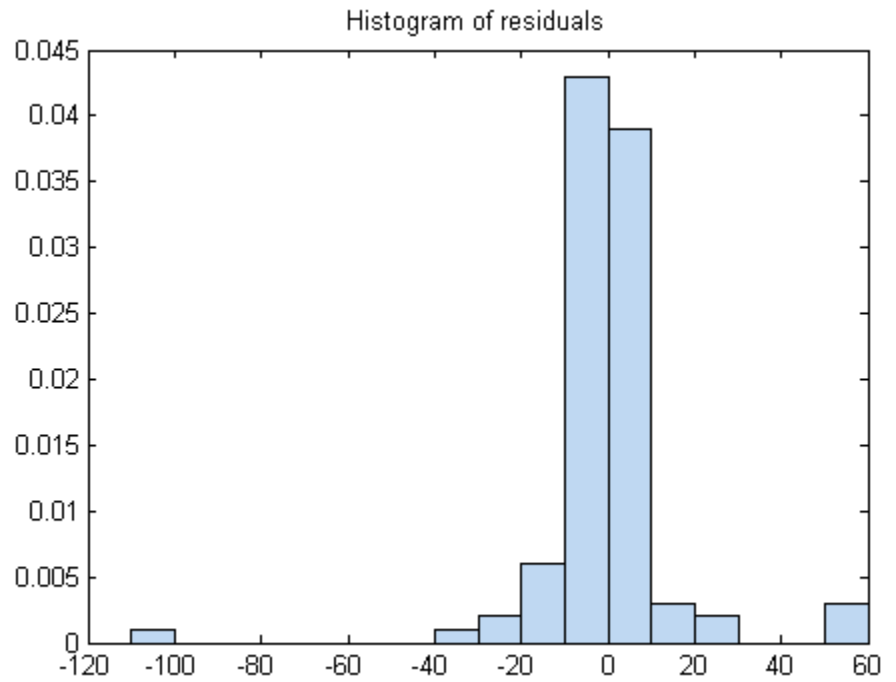
Create a generalized linear regression model of Poisson data.

```
mdl = GeneralizedLinearModel.fit(X,y,...
    'y ~ x1 + x2','distr','poisson');
```

Create a default residuals plot.

```
plotResiduals(mdl)
```

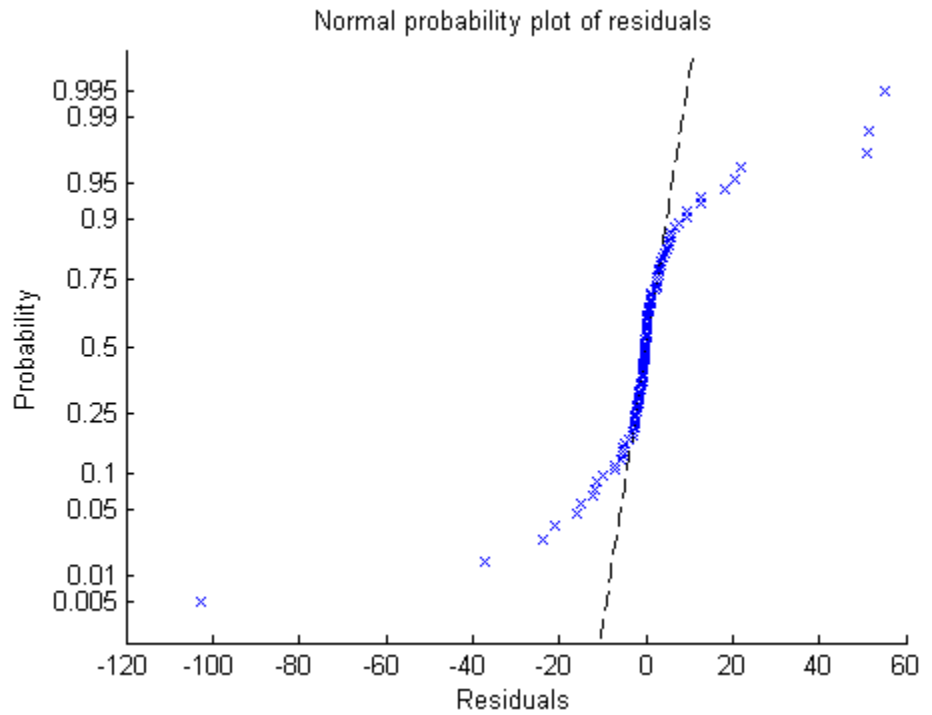
GeneralizedLinearModel.plotResiduals



Create a probability plot.

```
plotResiduals mdl, 'probability'
```

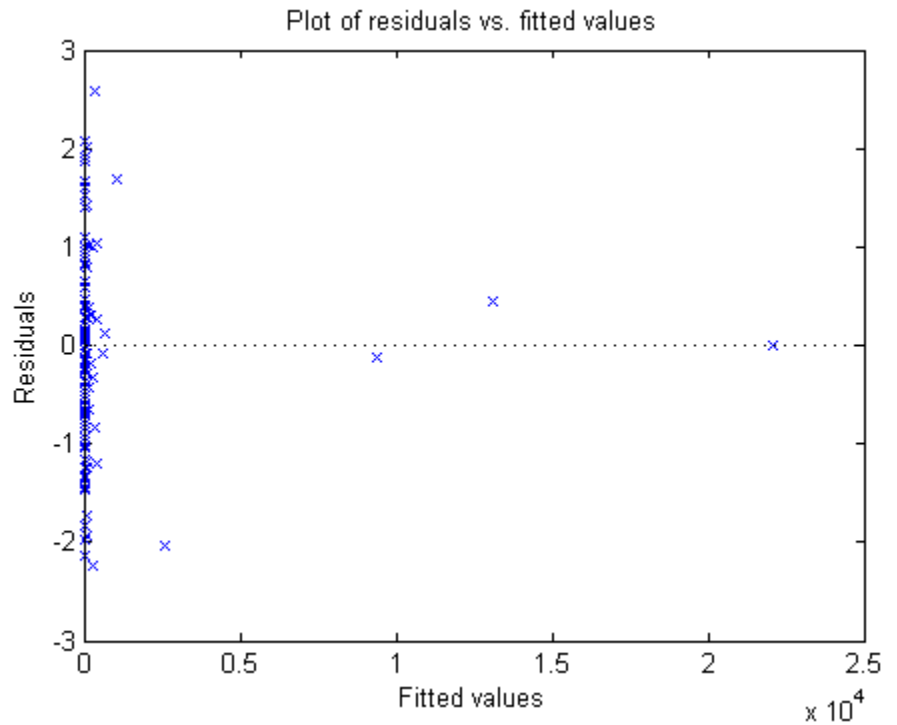
GeneralizedLinearModel.plotResiduals



The residuals do not match a normal distribution in the tails—they are more spread out.

Create a plot of the fitted residuals of Anscombe type.

GeneralizedLinearModel.plotResiduals



See Also [GeneralizedLinearModel |](#)

Related Examples

- “Residuals — Model Quality for Training Data” on page 9-158

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.plotResiduals

Purpose Plot residuals of linear regression model

Syntax

```
plotResiduals mdl
plotResiduals mdl, plottype
h = plotResiduals(...)
h = plotResiduals mdl, plottype, Name, Value
```

Description

`plotResiduals mdl` gives a histogram plot of the residuals of the `mdl` linear model.

`plotResiduals mdl, plottype` plots residuals in a plot of type `plottype`.

`h = plotResiduals(...)` returns handles to the lines in the plot.

`h = plotResiduals mdl, plottype, Name, Value` plots with additional options specified by one or more `Name, Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the x and y values for any data point, along with the observation name or number.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

plottype

String specifying the type of plot:

'caseorder'	Residuals vs. case (row) order
'fitted'	Residuals vs. fitted values
'histogram'	Histogram
'lagged'	Residuals vs. lagged residual ($r(t)$ vs. $r(t-1)$)

'probability'	Normal probability plot
'symmetry'	Symmetry plot

Default: 'histogram'

Name-Value Pair Arguments

Specify optional comma-separated pairs of **Name**, **Value** arguments, where **Name** is the argument name and **Value** is the corresponding value. **Name** must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as **Name1**, **Value1**, ..., **NameN**, **ValueN**.

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

LinearModel.plotResiduals

MarkerFaceColor

Color of the marker face for filled markers, a string or ColorSpec specification. For details, see `linespec`.

MarkerSize

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

ResidualType

Type of residual used in the plot:

'Raw'	Observed minus fitted values
'Pearson'	Raw residuals divided by RMSE
'Standardized'	Raw residuals divided by their estimated standard deviation
'Studentized'	Raw residuals divided by an independent (delete-1) estimate of their standard deviation

Default: 'Raw'

Output Arguments

h

Vector of handles to lines or patches in the plot.

Examples

Linear Residuals Plot

Plot the residuals of a fitted linear model.

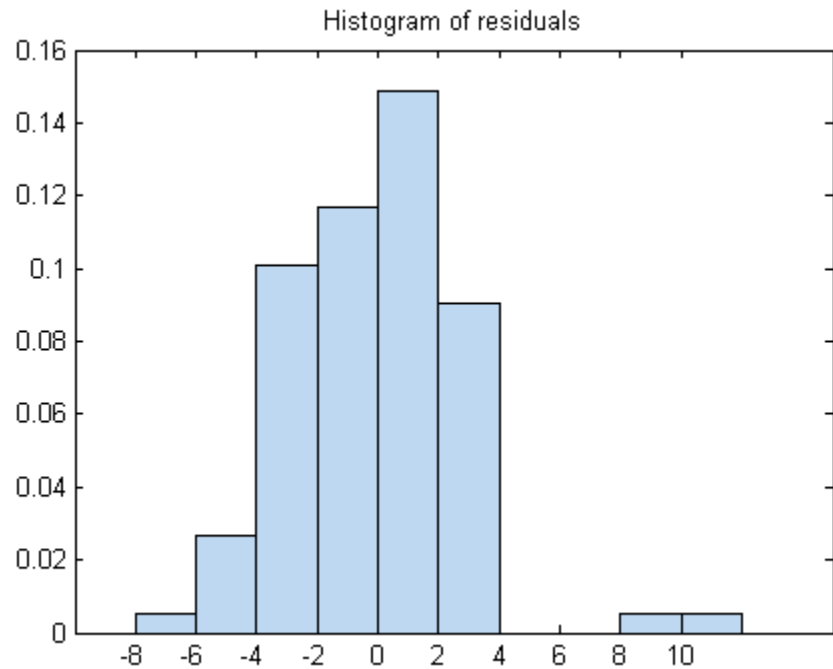
Load the `carsmall` data and fit a linear model of the mileage as a function of model year, weight, and weight squared.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
```

```
mdl = LinearModel.fit(ds, 'MPG ~ Year + Weight^2');
```

Plot the raw residuals.

```
plotResiduals(mdl)
```



Residual Probability Plot

Create a normal probability plot of the residuals of a fitted linear model.

Load the `carsmall` data and fit a linear model of the mileage as a function of model year, weight, and weight squared.

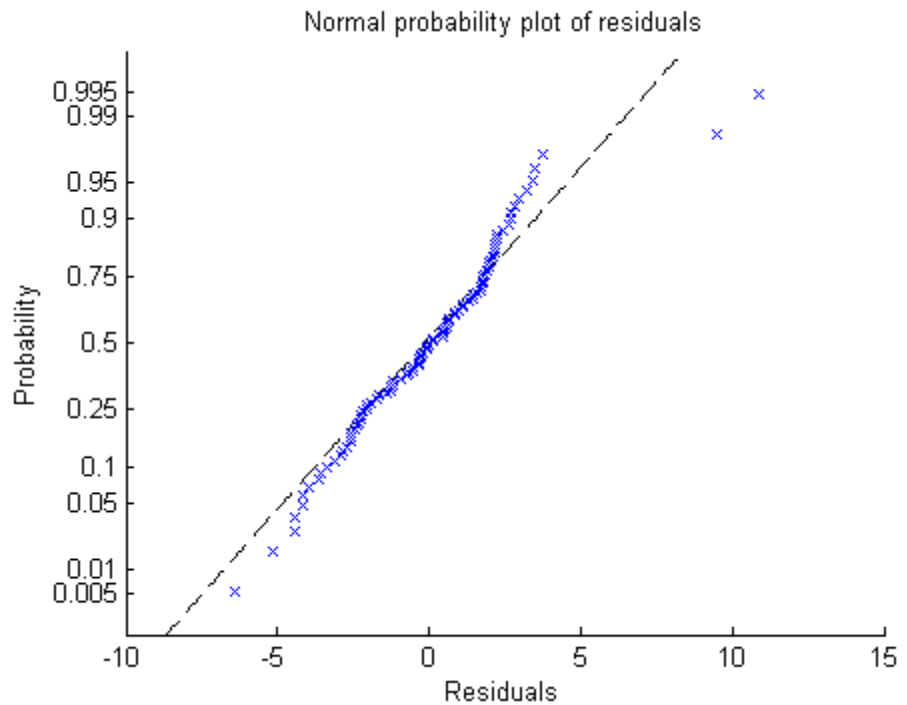
```
load carsmall  
X = [Weight, Model_Year];  
mdl = LinearModel.fit(X, MPG, ...
```

LinearModel.plotResiduals

```
'y ~ x2 + x1^2', 'Categorical', 2);
```

Create a normal probability plot of the residuals of the fitted model.

```
plotResiduals mdl, 'probability')
```



Alternatives

The `mdl.Residuals` dataset array contains the information in residual plots.

See Also

[LinearModel | plotDiagnostics](#)

Tutorials

- “Residuals — Model Quality for Training Data” on page 9-21
- “Linear Regression Workflow” on page 9-40

- “Compare large and small stepwise models” on page 9-108
- “Robust Regression versus Standard Least-Squares Fit” on page 9-113

How To

- “Linear Regression” on page 9-7

NonLinearModel.plotResiduals

Purpose Plot residuals of nonlinear regression model

Syntax

```
plotResiduals mdl
plotResiduals mdl,plottype
h = plotResiduals(...)
h = plotResiduals mdl,plottype,Name,Value)
```

Description

`plotResiduals(mdl)` gives a histogram plot of the residuals of the `mdl` nonlinear model.

`plotResiduals(mdl,plottype)` plots residuals in a plot of type `plottype`.

`h = plotResiduals(...)` returns handles to the lines in the plot.

`h = plotResiduals(mdl,plottype,Name,Value)` plots with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For many plots, the Data Cursor tool in the figure window displays the x and y values for any data point, along with the observation name or number.

Input Arguments

mdl

Nonlinear regression model, constructed by `NonLinearModel.fit`.

plottype

String specifying the type of plot:

'caseorder'	Residuals vs. case (row) order
'fitted'	Residuals vs. fitted values
'histogram'	Histogram
'lagged'	Residuals vs. lagged residual ($r(t)$ vs. $r(t-1)$)
'probability'	Normal probability plot
'symmetry'	Symmetry plot

Default: 'histogram'

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Note The plot property name-value pairs apply to the first returned handle `h(1)`.

Color

Color of the line or marker, a string or `ColorSpec` specification. For details, see `linespec`.

LineStyle

Type of line, a string or `lineseriesproperties` specification. For details, see `linespec`.

LineWidth

Width of the line or edges of filled area, in points, a positive scalar. One point is 1/72 inch.

Default: 0.5

MarkerEdgeColor

Color of the marker or edge color for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

MarkerFaceColor

Color of the marker face for filled markers, a string or `ColorSpec` specification. For details, see `linespec`.

NonLinearModel.plotResiduals

MarkerSize

Size of the marker in points, a strictly positive scalar. One point is 1/72 inch.

ResidualType

Type of residual used in the plot:

'Raw'	Observed minus fitted values
'Pearson'	Raw residuals divided by RMSE
'Standardized'	Raw residuals divided by their estimated standard deviation
'Studentized'	Raw residuals divided by an independent (delete-1) estimate of their standard deviation

Default: 'Raw'

Output Arguments

h

Vector of handles to lines or patches in the plot.

Examples

Residual Plot

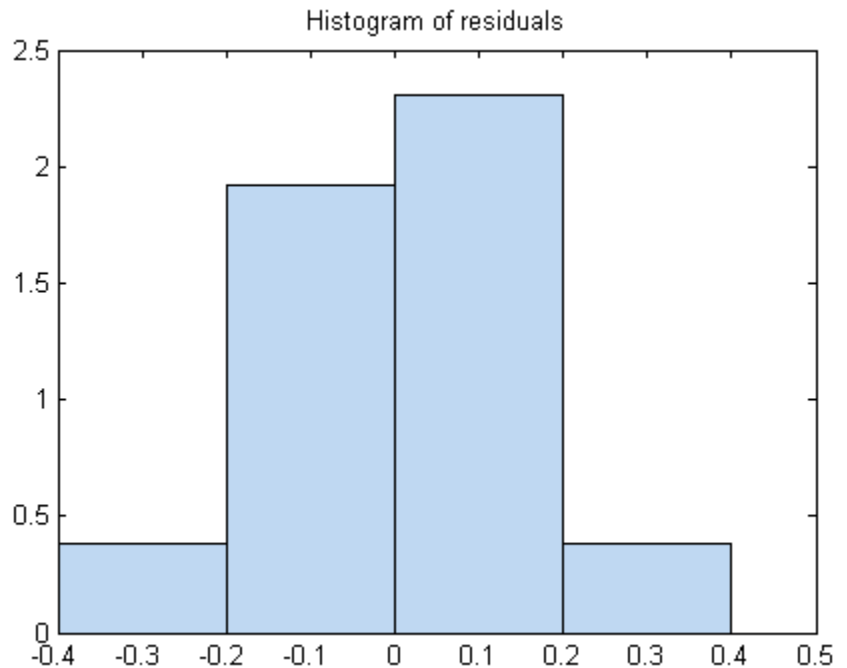
Plot the residuals of a fitted nonlinear model.

Load the reaction data and fit a model of the reaction rate as a function of reactants.

```
load reaction
mdl = NonLinearModel.fit(reactants,...
    rate,@hougen,[1 .05 .02 .1 2]);
```

Plot the residuals of the fitted model.

```
plotResiduals(mdl)
```

Residual Probability Plot

Create a normal probability plot of the residuals of a fitted nonlinear model.

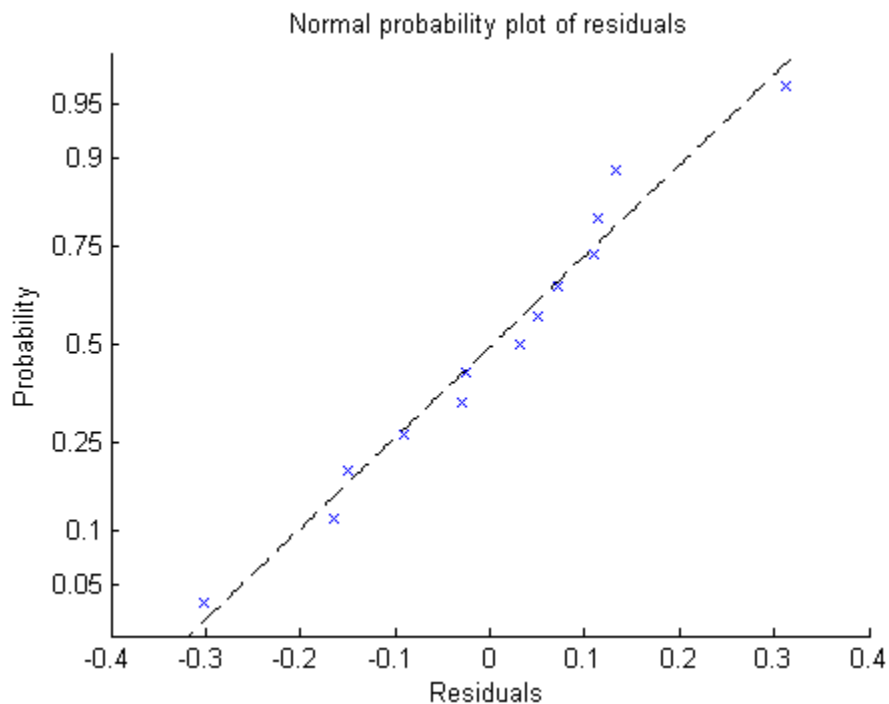
Load the reaction data and fit a model of the reaction rate as a function of reactants.

```
load reaction
mdl = NonLinearModel.fit(reactants,...
    rate,@hougen,[1 .05 .02 .1 2]);
```

Create a normal probability plot of the residuals of the fitted model.

```
plotResiduals(mdl,'probability')
```

NonLinearModel.plotResiduals



See Also

`NonLinearModel | plotDiagnostics |`

Related Examples

- “Examine Quality and Adjust the Fitted Model” on page 9-202
- “Nonlinear Regression Workflow” on page 9-210

Concepts

- “Nonlinear Regression” on page 9-196

Purpose	Plot of slices through fitted generalized linear regression surface
Syntax	<pre>plotSlice mdl h = plotSlice mdl</pre>
Description	<p><code>plotSlice(mdl)</code> creates a new figure containing a series of plots, each representing a slice through the regression surface predicted by <code>mdl</code>. For each plot, the surface slice is shown as a function of a single predictor variable, with the other predictor variables held constant.</p> <p><code>h = plotSlice(mdl)</code> returns handles to the lines in the plot.</p>
Tips	<ul style="list-style-type: none">• If there are more than eight predictors, <code>plotSlice</code> selects the first five for plotting. Use the Predictors menu to control which predictors are plotted.• The Bounds menu lets you choose between simultaneous or non-simultaneous bounds, and between bounds on the function or bounds on a new observation.
Input Arguments	<p>mdl</p> <p>Generalized linear model, as constructed by <code>GeneralizedLinearModel.fit</code> or <code>GeneralizedLinearModel.stepwise</code>.</p>
Output Arguments	<p>h</p> <p>Vector of handles to lines or patches in the plot.</p>
Examples	<p>Slice Plot of Generalized Linear Regression Model</p> <p>Create a slice plot of a Poisson generalized linear model.</p> <p>Generate artificial data for the model using Poisson random numbers with two underlying predictors $X(1)$ and $X(2)$.</p> <pre>rng('default') % for reproducibility rndvars = randn(100,2);</pre>

GeneralizedLinearModel.plotSlice

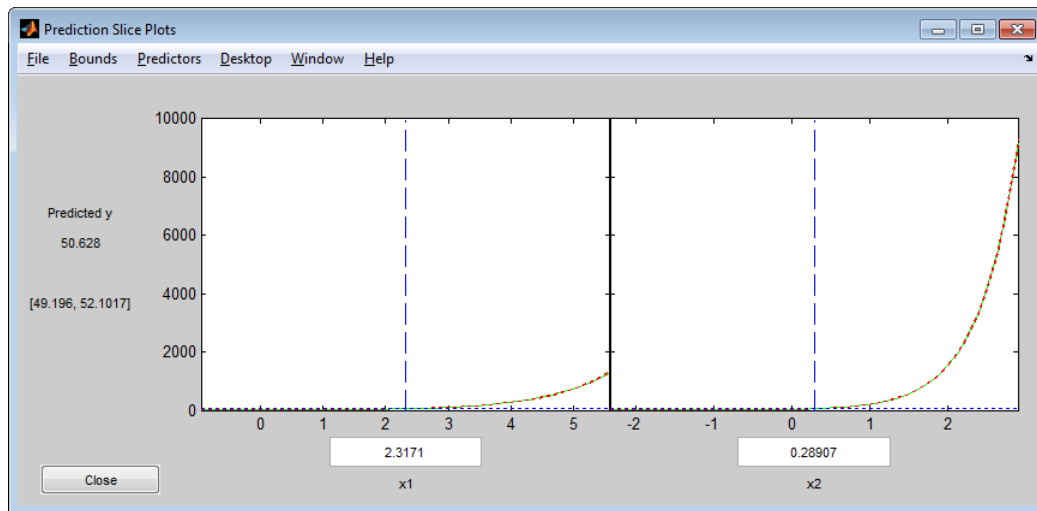
```
X = [2+randvars(:,1),randvars(:,2)];  
mu = exp(1 + X*[1;2]);  
y = poissrnd(mu);
```

Create a generalized linear regression model of Poisson data.

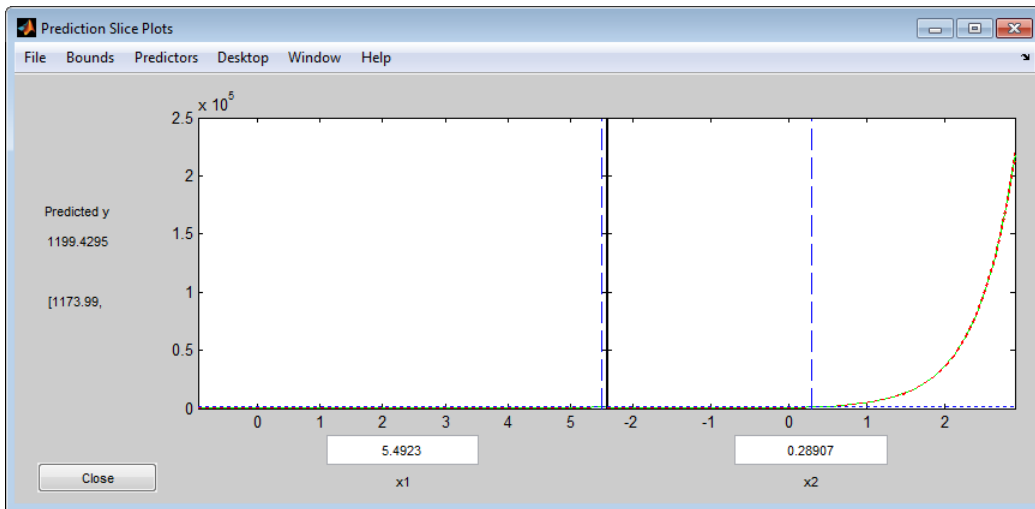
```
mdl = GeneralizedLinearModel.fit(X,y,...  
    'y ~ x1 + x2','distr','poisson');
```

Create the slice plot.

```
plotSlice(mdl)
```



Drag the x1 prediction line to the right and view the changes in the prediction and the response curve for the x2 predictor.



See Also

`GeneralizedLinearModel | predict |`

Related Examples

- “Diagnostic Plots” on page 9-155
- “Plots to Understand Predictor Effects and How to Modify a Model” on page 9-161

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.plotSlice

Purpose Plot of slices through fitted linear regression surface

Syntax `plotSlice mdl`
`h = plotSlice mdl`

Description `plotSlice mdl` creates a new figure containing a series of plots, each representing a slice through the regression surface predicted by `mdl`. For each plot, the surface slice is shown as a function of a single predictor variable, with the other predictor variables held constant.

`h = plotSlice mdl` returns handles to the lines in the plot.

Tips

- If there are more than eight predictors, `plotSlice` selects the first five for plotting. Use the **Predictors** menu to control which predictors are plotted.
- The **Bounds** menu lets you choose between simultaneous or non-simultaneous bounds, and between bounds on the function or bounds on a new observation.

Input Arguments **mdl**

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

Output Arguments **h**

Vector of handles to lines or patches in the plot.

Examples **Slice Plot**

Plot the slices through a fitted linear model.

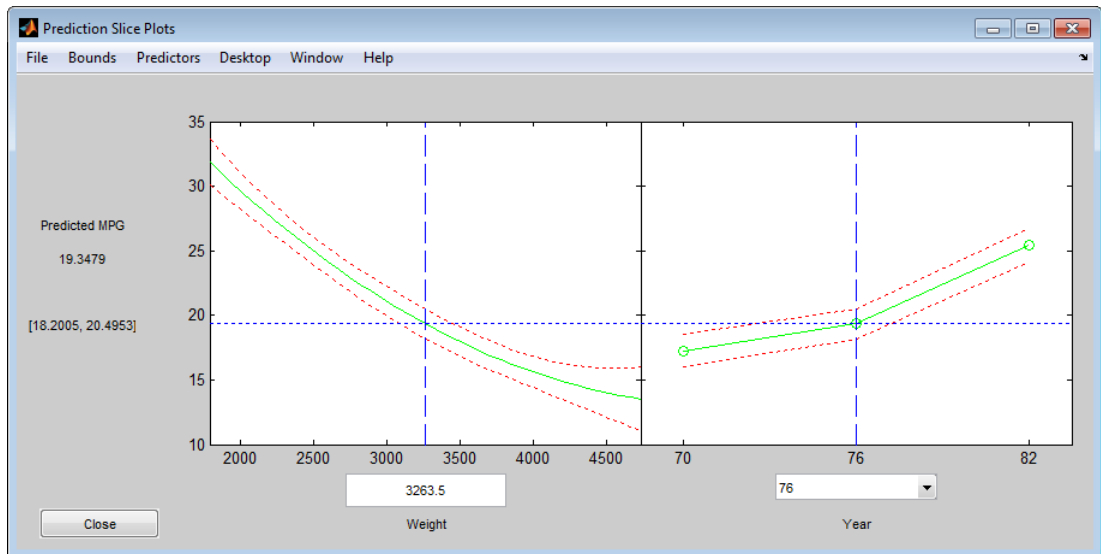
Load the `carsmall` data and fit a linear model of the mileage as a function of model year, weight, and weight squared.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
```

```
mdl = LinearModel.fit(ds, 'MPG ~ Year + Weight^2');
```

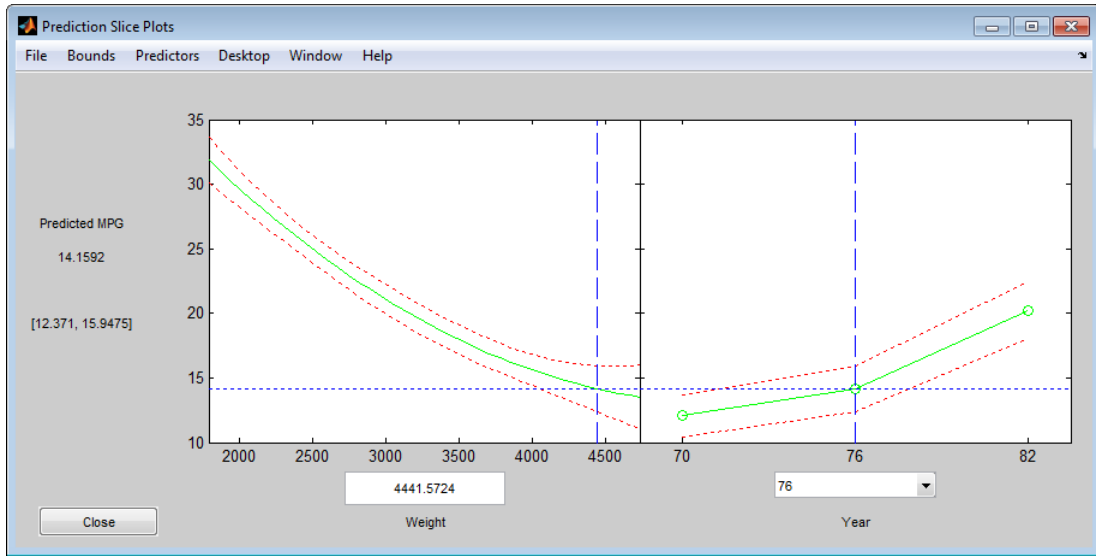
Create a slice plot.

```
plotSlice(mdl)
```



Drag the `Weight` prediction line to the right and observe the change in the predicted MPG and the response curve for `Year`.

LinearModel.plotSlice



See Also

`LinearModel | predict`

Tutorials

- “Plots to Understand Predictor Effects” on page 9-26

How To

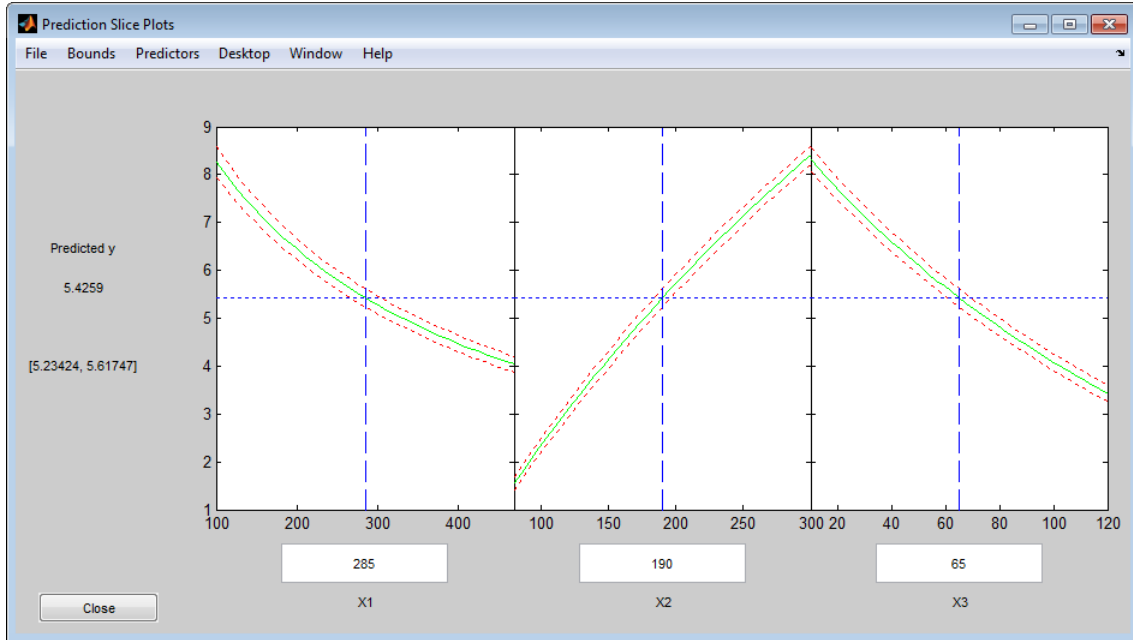
- “Linear Regression” on page 9-7

Purpose	Plot of slices through fitted nonlinear regression surface
Syntax	<pre>plotSlice mdl h = plotSlice mdl</pre>
Description	<p><code>plotSlice(mdl)</code> creates a new figure containing a series of plots, each representing a slice through the regression surface predicted by <code>mdl</code>. For each plot, the surface slice is shown as a function of a single predictor variable, with the other predictor variables held constant.</p> <p><code>h = plotSlice(mdl)</code> returns handles to the lines in the plot.</p>
Tips	<ul style="list-style-type: none">• If there are more than eight predictors, <code>plotSlice</code> selects the first five for plotting. Use the Predictors menu to control which predictors are plotted.• The Bounds menu lets you choose between simultaneous or non-simultaneous bounds, and between bounds on the function or bounds on a new observation.
Input Arguments	<p>mdl</p> <p>Nonlinear regression model, constructed by <code>NonLinearModel.fit</code>.</p>
Output Arguments	<p>h</p> <p>Vector of handles to lines or patches in the plot.</p>
Examples	<p>Slice Plot</p> <p>Plot slices of a fitted nonlinear model.</p> <p>Load the reaction data and fit a model of the reaction rate as a function of reactants.</p> <pre>load reaction mdl = NonLinearModel.fit(reactants,... rate,@hougen,[1 .05 .02 .1 2]);</pre>

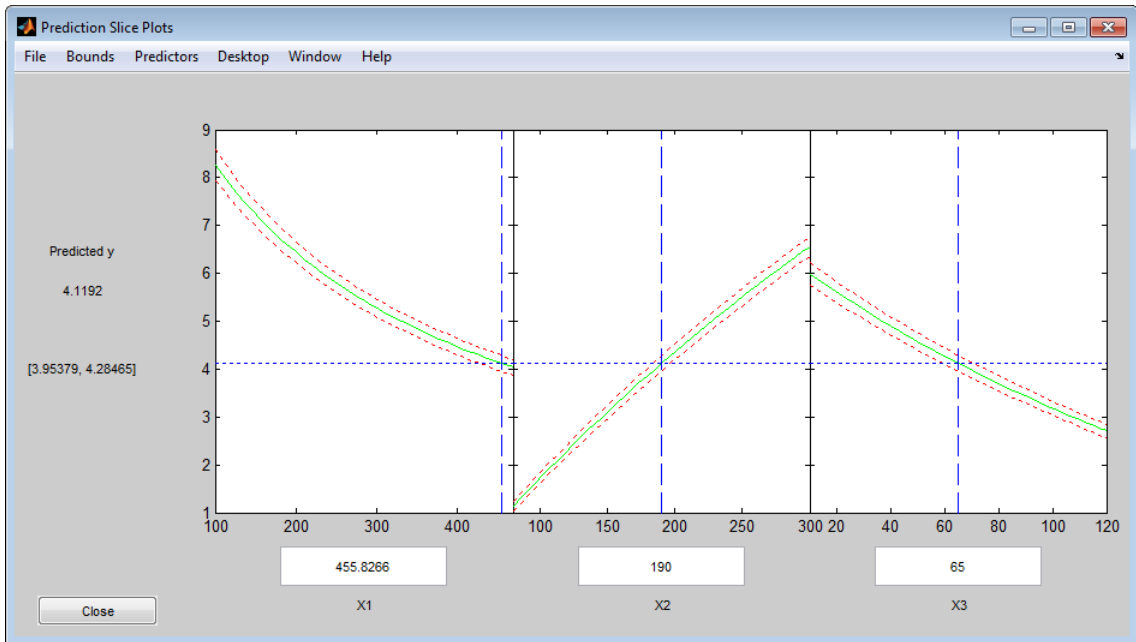
NonLinearModel.plotSlice

Create a slice plot

```
plotSlice mdl
```



Drag the X1 prediction line to the right, and observe the change in the predicted response y and in the predicted response curves to X2 and X3.



See Also

`NonLinearModel | predict |`

Related Examples

- “Examine Quality and Adjust the Fitted Model” on page 9-202
- “Predict or Simulate Responses to New Data” on page 9-206
- “Nonlinear Regression Workflow” on page 9-210

Concepts

- “Nonlinear Regression” on page 9-196

Purpose

Partial least-squares regression

Syntax

```
[XL,YL] = plsregress(X,Y,ncomp)
[XL,YL,XS] = plsregress(X,Y,ncomp)
[XL,YL,XS,YS] = plsregress(X,Y,ncomp)
[XL,YL,XS,YS,BETA] = PLSREGRESS(X,Y,ncomp,...)
[XL,YL,XS,YS,BETA,PCTVAR] = plsregress(X,Y,ncomp)
[XL,YL,XS,YS,BETA,PCTVAR,MSE] = plsregress(X,Y,ncomp)
[XL,YL,XS,YS,BETA,PCTVAR,MSE] = plsregress(...,param1,val1,
    param2,val2,...)
[XL,YL,XS,YS,BETA,PCTVAR,MSE,stats] = PLSREGRESS(X,Y,ncomp,
    ...)
```

Description

`[XL,YL] = plsregress(X,Y,ncomp)` computes a partial least-squares (PLS) regression of Y on X , using $ncomp$ PLS components, and returns the predictor and response loadings in XL and YL , respectively. X is an n -by- p matrix of predictor variables, with rows corresponding to observations and columns to variables. Y is an n -by- m response matrix. XL is a p -by- $ncomp$ matrix of predictor loadings, where each row contains coefficients that define a linear combination of PLS components that approximate the original predictor variables. YL is an m -by- $ncomp$ matrix of response loadings, where each row contains coefficients that define a linear combination of PLS components that approximate the original response variables.

`[XL,YL,XS] = plsregress(X,Y,ncomp)` returns the predictor scores XS , that is, the PLS components that are linear combinations of the variables in X . XS is an n -by- $ncomp$ orthonormal matrix with rows corresponding to observations and columns to components.

`[XL,YL,XS,YS] = plsregress(X,Y,ncomp)` returns the response scores YS , that is, the linear combinations of the responses with which the PLS components XS have maximum covariance. YS is an n -by- $ncomp$ matrix with rows corresponding to observations and columns to components. YS is neither orthogonal nor normalized.

`plsregress` uses the SIMPLS algorithm, first centering X and Y by subtracting off column means to get centered variables $X0$ and $Y0$.

However, it does not rescale the columns. To perform PLS with standardized variables, use `zscore` to normalize `X` and `Y`.

If `ncomp` is omitted, its default value is `min(size(X,1)-1,size(X,2))`.

The relationships between the scores, loadings, and centered variables `X0` and `Y0` are:

$$XL = (XS \setminus X0)' = X0' * XS,$$

$$YL = (XS \setminus Y0)' = Y0' * XS,$$

`XL` and `YL` are the coefficients from regressing `X0` and `Y0` on `XS`, and `XS*XL'` and `XS*YL'` are the PLS approximations to `X0` and `Y0`.

`plsregress` initially computes `YS` as:

$$YS = Y0 * YL = Y0 * Y0' * XS,$$

By convention, however, `plsregress` then orthogonalizes each column of `YS` with respect to preceding columns of `XS`, so that `XS' * YS` is lower triangular.

`[XL, YL, XS, YS, BETA] = PLSREGRESS(X, Y, ncomp, ...)` returns the PLS regression coefficients `BETA`. `BETA` is a $(p+1)$ -by- m matrix, containing intercept terms in the first row:

$$Y = [\text{ones}(n, 1), X] * BETA + Y_{\text{residuals}},$$

`Y0 = X0 * BETA(2:end, :) + Y_{\text{residuals}}`. Here `Y_{\text{residuals}}` is the vector of response residuals.

`[XL, YL, XS, YS, BETA, PCTVAR] = plsregress(X, Y, ncomp)` returns a 2-by-`ncomp` matrix `PCTVAR` containing the percentage of variance explained by the model. The first row of `PCTVAR` contains the percentage of variance explained in `X` by each PLS component, and the second row contains the percentage of variance explained in `Y`.

`[XL, YL, XS, YS, BETA, PCTVAR, MSE] = plsregress(X, Y, ncomp)` returns a 2-by- $(ncomp+1)$ matrix `MSE` containing estimated mean-squared errors for PLS models with 0:`ncomp` components. The first row of `MSE` contains mean-squared errors for the predictor variables in `X`, and the second row contains mean-squared errors for the response variable(s) in `Y`.

plsregress

[XL,YL,XS,YS,BETA,PCTVAR,MSE] =
plsregress(...,param1,val1,param2,val2,...) specifies optional
parameter name/value pairs from the following table to control the
calculation of MSE.

Parameter	Value
'cv'	<p>The method used to compute MSE.</p> <ul style="list-style-type: none">• When the value is a positive integer <i>k</i>, plsregress uses <i>k</i>-fold cross-validation.• When the value is an object of the <code>cvpartition</code> class, other forms of cross-validation can be specified.• When the value is 'resubstitution', plsregress uses <i>X</i> and <i>Y</i> both to fit the model and to estimate the mean-squared errors, without cross-validation. <p>The default is 'resubstitution'.</p>
'mcreps'	<p>A positive integer indicating the number of Monte-Carlo repetitions for cross-validation. The default value is 1. The value must be 1 if the value of 'cv' is 'resubstitution'.</p>
options	<p>A structure that specifies whether to run in parallel, and specifies the random stream or streams. Create the options structure with <code>statset</code>. Option fields:</p> <ul style="list-style-type: none">• <code>UseParallel</code> — Set to 'always' to compute in parallel. Default is 'never'.• <code>UseSubstreams</code> — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set <code>Streams</code> to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'.• <code>Streams</code> — A <code>RandStream</code> object or cell array consisting of one such object. If you do not specify <code>Streams</code>, plsregress uses the default stream.

```
[XL,YL,XS,YS,BETA,PCTVAR,MSE,stats] =  
PLSREGRESS(X,Y,ncomp,...) returns a structure stats with the  
following fields:
```

- **W** — A p -by- $ncomp$ matrix of PLS weights so that $X_S = X_0 * W$.
- **T2** — The T^2 statistic for each point in X_S .
- **Xresiduals** — The predictor residuals, that is, $X_0 - X_S * X_L'$.
- **Yresiduals** — The response residuals, that is, $Y_0 - X_S * Y_L'$.

Examples

Load data on near infrared (NIR) spectral intensities of 60 samples of gasoline at 401 wavelengths, and their octane ratings:

```
load spectra  
X = NIR;  
y = octane;
```

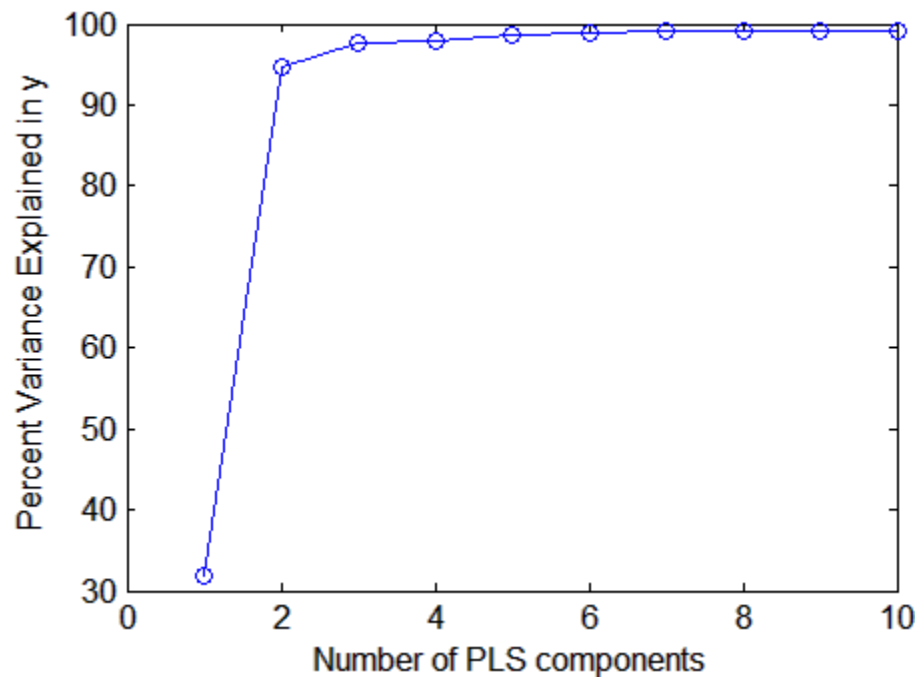
Perform PLS regression with ten components:

```
[XL,y1,XS,YS,beta,PCTVAR] = plsregress(X,y,10);
```

Plot the percent of variance explained in the response variable as a function of the number of components:

```
plot(1:10,cumsum(100*PCTVAR(2,:)),'-bo');  
xlabel('Number of PLS components');  
ylabel('Percent Variance Explained in y');
```

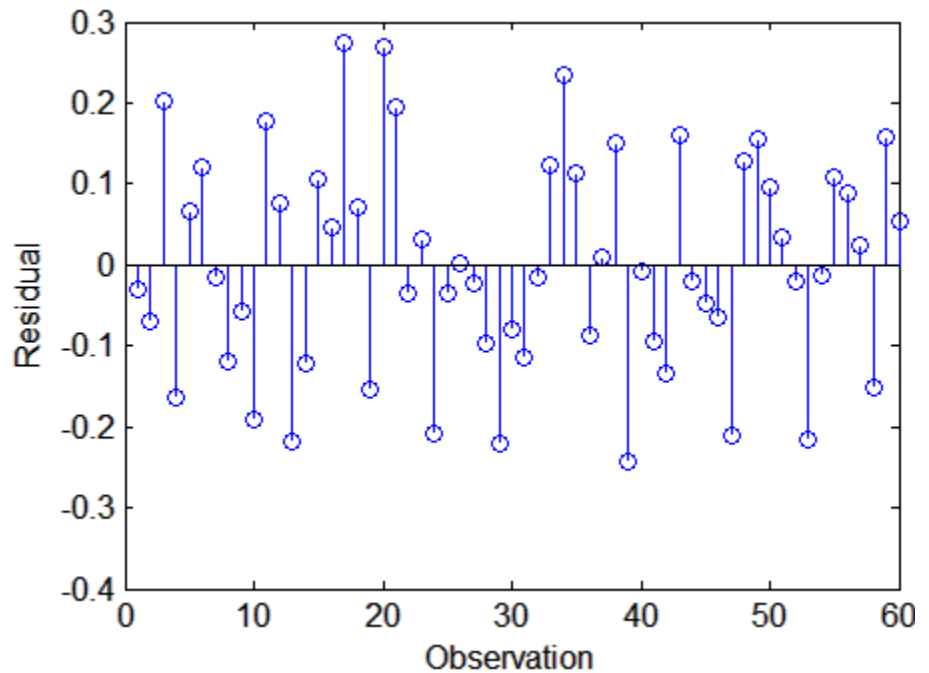
plsregress



Compute the fitted response and display the residuals:

```
yfit = [ones(size(X,1),1) X]*beta;  
residuals = y-yfit;
```

```
stem(residuals)  
xlabel('Observation');  
ylabel('Residual');
```

References

[1] de Jong, S. “SIMPLS: An Alternative Approach to Partial Least Squares Regression.” *Chemometrics and Intelligent Laboratory Systems*. Vol. 18, 1993, pp. 251–263.

[2] Rosipal, R., and N. Kramer. “Overview and Recent Advances in Partial Least Squares.” *Subspace, Latent Structure and Feature Selection: Statistical and Optimization Perspectives Workshop (SLSFS 2005), Revised Selected Papers (Lecture Notes in Computer Science 3940)*. Berlin, Germany: Springer-Verlag, 2006, pp. 34–51.

See Also

regress | sequentialfs

sobolset.PointOrder property

Purpose Point generation method

Description The `PointOrder` property contains a string that specifies the order in which the Sobol sequence points are produced. The property value must be one of 'standard' or 'graycode'. When set to 'standard' the points produced match the original Sobol sequence implementation. When set to 'graycode', the sequence is generated using an implementation that uses the Gray code of the index instead of the index itself.

Purpose

Point set from which stream is drawn

Description

The PointSet property contains a copy of the point set from which the stream is providing points. The point set is specified during construction of a quasi-random stream and cannot subsequently be altered.

Examples

```
Q = grandstream('sobol', 5, 'Skip', 8);  
% Create a new stream based on the same sequence as that in Q  
Q2 = grandstream(Q.PointSet);  
u1 = rand(Q, 10)  
u2 = rand(Q2, 10) % contains exactly the same values as u1
```

poisscdf

Purpose Poisson cumulative distribution function

Syntax `P = poisscdf(X,lambda)`

Description `P = poisscdf(X,lambda)` computes the Poisson cdf at each of the values in `X` using the corresponding mean parameters in `lambda`. `X` and `lambda` can be vectors, matrices, or multidimensional arrays that have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input. The parameters in `lambda` must be positive.

The Poisson cdf is

$$p = F(x | \lambda) = e^{-\lambda} \sum_{i=0}^{\text{floor}(x)} \frac{\lambda^i}{i!}$$

Examples

For example, consider a Quality Assurance department that performs random tests of individual hard disks. Their policy is to shut down the manufacturing process if an inspector finds more than four bad sectors on a disk. What is the probability of shutting down the process if the mean number of bad sectors (λ) is two?

```
probability = 1-poisscdf(4,2)
probability =
    0.0527
```

About 5% of the time, a normally functioning manufacturing process produces more than four flaws on a hard disk.

Suppose the average number of flaws (λ) increases to four. What is the probability of finding fewer than five flaws on a hard drive?

```
probability = poisscdf(4,4)
probability =
    0.6288
```

This means that this faulty manufacturing process continues to operate after this first inspection almost 63% of the time.

See Also

[cdf](#) | [poisspdf](#) | [poissinv](#) | [poisstat](#) | [poissfit](#) | [poissrnd](#)

How To

- “Poisson Distribution” on page B-102

poissfit

Purpose Poisson parameter estimates

Syntax
`lambdahat = poissfit(data)`
`[lambdahat,lambdaci] = poissfit(data)`
`[lambdahat,lambdaci] = poissfit(data,alpha)`

Description `lambdahat = poissfit(data)` returns the maximum likelihood estimate (MLE) of the parameter of the Poisson distribution, λ , given the data `data`.
`[lambdahat,lambdaci] = poissfit(data)` also gives 95% confidence intervals in `lambdaci`.
`[lambdahat,lambdaci] = poissfit(data,alpha)` gives 100(1 - alpha)% confidence intervals. For example `alpha = 0.001` yields 99.9% confidence intervals.
The sample mean is the MLE of λ .

$$\hat{\lambda} = \frac{1}{n} \sum_{i=1}^n x_i$$

Examples

```
r = poissrnd(5,10,2);  
[l,lci] = poissfit(r)  
l =  
    7.4000    6.3000  
lci =  
    5.8000    4.8000  
    9.1000    7.9000
```

See Also `mle` | `poisspdf` | `poisscdf` | `poissinv` | `poisstat` | `poissrnd`

How To • “Poisson Distribution” on page B-102

Purpose Poisson inverse cumulative distribution function

Syntax `X = poissinv(P,lambda)`

Description `X = poissinv(P,lambda)` returns the smallest value X such that the Poisson cdf evaluated at X equals or exceeds P , using mean parameters in `lambda`. `P` and `lambda` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input.

Examples If the average number of defects (λ) is two, what is the 95th percentile of the number of defects?

```
poissinv(0.95,2)
ans =
     5
```

What is the median number of defects?

```
median_defects = poissinv(0.50,2)
median_defects =
     2
```

See Also `icdf` | `poisscdf` | `poisspdf` | `poisstat` | `poissfit` | `poissrnd`

How To • “Poisson Distribution” on page B-102

poisspdf

Purpose Poisson probability density function

Syntax `Y = poisspdf(X,lambda)`

Description `Y = poisspdf(X,lambda)` computes the Poisson pdf at each of the values in `X` using mean parameters in `lambda`. `X` and `lambda` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other input. The parameters in `lambda` must all be positive.

The Poisson pdf is

$$y = f(x | \lambda) = \frac{\lambda^x}{x!} e^{-\lambda} I_{(0,1,\dots)}(x)$$

where x can be any nonnegative integer. The density function is zero unless x is an integer.

Examples A computer hard disk manufacturer has observed that flaws occur randomly in the manufacturing process at the average rate of two flaws in a 4 GB hard disk and has found this rate to be acceptable. What is the probability that a disk will be manufactured with no defects?

In this problem, $\lambda = 2$ and $x = 0$.

```
p = poisspdf(0,2)
p =
    0.1353
```

See Also `pdf` | `poisscdf` | `poissinv` | `poisstat` | `poissfit` | `poissrnd`

How To • “Poisson Distribution” on page B-102

Purpose	Poisson random numbers
Syntax	<pre>R = poissrnd(lambda) R = poissrnd(lambda,m,n,...) R = poissrnd(lambda,[m,n,...])</pre>
Description	<p>R = poissrnd(lambda) generates random numbers from the Poisson distribution with mean parameter lambda. lambda can be a vector, a matrix, or a multidimensional array. The size of R is the size of lambda.</p> <p>R = poissrnd(lambda,m,n,...) or R = poissrnd(lambda,[m,n,...]) generates an m-by-n-by-... array. The lambda parameter can be a scalar or an array of the same size as R.</p>
Examples	<p>Generate a random sample of 10 pseudo-observations from a Poisson distribution with $\lambda = 2$.</p> <pre>lambda = 2; random_sample1 = poissrnd(lambda,1,10) random_sample1 = 1 0 1 2 1 3 4 2 0 0 random_sample2 = poissrnd(lambda,[1 10]) random_sample2 = 1 1 1 5 0 3 2 2 3 4 random_sample3 = poissrnd(lambda(ones(1,10))) random_sample3 = 3 2 1 1 0 0 4 0 2 0</pre>
See Also	random poisspdf poisscdf poissinv poisstat poissfit
How To	• “Poisson Distribution” on page B-102

poisstat

Purpose Poisson mean and variance

Syntax `M = poisstat(lambda)`
`[M,V] = poisstat(lambda)`

Description `M = poisstat(lambda)` returns the mean of the Poisson distribution using mean parameters in `lambda`. The size of `M` is the size of `lambda`.
`[M,V] = poisstat(lambda)` also returns the variance `V` of the Poisson distribution.
For the Poisson distribution with parameter λ , both the mean and variance are equal to λ .

Examples Find the mean and variance for the Poisson distribution with $\lambda = 2$.

```
[m,v] = poisstat([1 2; 3 4])  
m =  
    1    2  
    3    4  
v =  
    1    2  
    3    4
```

See Also `poisspdf` | `poisscdf` | `poissinv` | `poissfit` | `poissrnd`

How To • “Poisson Distribution” on page B-102

Purpose Polynomial confidence intervals

Syntax

```
Y = polyconf(p,X)
[Y,DELTA] = polyconf(p,X,S)
[Y,DELTA] = polyconf(p,X,S,param1,val1,param2,val2,...)
```

Description

`Y = polyconf(p,X)` evaluates the polynomial `p` at the values in `X`. `p` is a vector of coefficients in descending powers.

`[Y,DELTA] = polyconf(p,X,S)` takes outputs `p` and `S` from `polyfit` and generates 95% prediction intervals `Y - DELTA` for new observations at the values in `X`.

`[Y,DELTA] = polyconf(p,X,S,param1,val1,param2,val2,...)` specifies optional parameter name/value pairs chosen from the following list.

Parameter	Value
'alpha'	A value between 0 and 1 specifying a confidence level of $100 * (1 - \text{alpha})\%$. The default is 0.05.
'mu'	A two-element vector containing centering and scaling parameters. With this option, <code>polyconf</code> uses $(X - \text{mu}(1)) / \text{mu}(2)$ in place of <code>X</code> .
'predopt'	Either 'observation' (the default) to compute prediction intervals for new observations at the values in <code>X</code> , or 'curve' to compute confidence intervals for the fit evaluated at the values in <code>X</code> . See below.
'simopt'	Either 'off' (the default) for nonsimultaneous bounds, or 'on' for simultaneous bounds. See below.

The 'predopt' and 'simopt' parameters can be understood in terms of the following functions:

- $p(x)$ — the unknown mean function estimated by the fit
- $l(x)$ — the lower confidence bound

- $u(x)$ — the upper confidence bound

Suppose you make a new observation y_{n+1} at x_{n+1} , so that

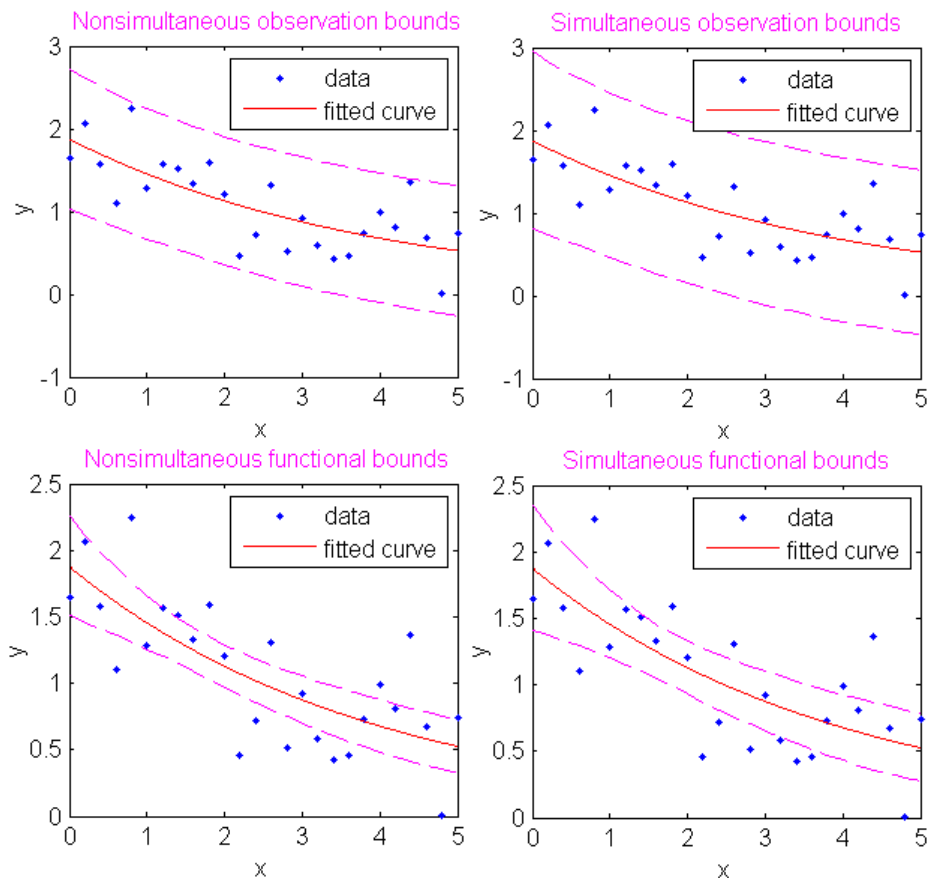
$$y_{n+1}(x_{n+1}) = p(x_{n+1}) + \varepsilon_{n+1}$$

By default, the interval $[l_{n+1}(x_{n+1}), u_{n+1}(x_{n+1})]$ is a 95% confidence bound on $y_{n+1}(x_{n+1})$.

The following combinations of the 'predopt' and 'simopt' parameters allow you to specify other bounds.

'simopt'	'predopt'	Bounded Quantity
'off'	'observation'	$y_{n+1}(x_{n+1})$ (default)
'off'	'curve'	$p(x_{n+1})$
'on'	'observation'	$y_{n+1}(x)$, for all x
'on'	'curve'	$p(x)$, for all x

In general, 'observation' intervals are wider than 'curve' intervals, because of the additional uncertainty of predicting a new response value (the curve plus random errors). Likewise, simultaneous intervals are wider than nonsimultaneous intervals, because of the additional uncertainty of bounding values for all predictors x .



Examples

This example uses code from the documentation example function `polydemo`, and calls the documentation example function `polystr` to convert the coefficient vector `p` into a string for the polynomial expression displayed in the figure title. It combines the functions `polyfit`, `polyval`, `roots`, and `polyconf` to produce a formatted display of data with a polynomial fit.

Note Statistics Toolbox documentation example files are located in the `\help\toolbox\stats\examples` subdirectory of your MATLAB root folder (`matlabroot`). This subdirectory is not on the MATLAB path at installation. To use the files in this subdirectory, either add the subdirectory to the MATLAB path (`addpath`) or make the subdirectory your current working folder (`cd`).

Display simulated data with a quadratic trend, a fitted quadratic polynomial, and 95% prediction intervals for new observations:

```
xdata = -5:5;
ydata = x.^2 - 5*x - 3 + 5*randn(size(x));

degree = 2; % Degree of the fit
alpha = 0.05; % Significance level

% Compute the fit and return the structure used by
% POLYCONF.
[p,S] = polyfit(xdata,ydata,degree);

% Compute the real roots and determine the extent of the
% data.
r = roots(p)'; % Roots as a row vector.
real_r = r(imag(r) == 0); % Real roots.

% Assure that the data are row vectors.
xdata = reshape(xdata,1,length(xdata));
ydata = reshape(ydata,1,length(ydata));

% Extent of the data.
mx = min([real_r,xdata]);
Mx = max([real_r,xdata]);
my = min([ydata,0]);
My = max([ydata,0]);
```

```

% Scale factors for plotting.
sx = 0.05*(Mx-mx);
sy = 0.05*(My-my);

% Plot the data, the fit, and the roots.
hdata = plot(xdata,ydata,'md','MarkerSize',5,...
    'LineWidth',2);
hold on
xfit = mx-sx:0.01:Mx+sx;
yfit = polyval(p,xfit);
hfit = plot(xfit,yfit,'b-','LineWidth',2);
hroots = plot(real_r,zeros(size(real_r)),...
    'bo','MarkerSize',5,...
    'LineWidth',2,...
    'MarkerFaceColor','b');

grid on
plot(xfit,zeros(size(xfit)),'k-','LineWidth',2)
axis([mx-sx Mx+sx my-sy My+sy])

% Add prediction intervals to the plot.
[Y,DELTA] = polyconf(p,xfit,S,'alpha',alpha);
hconf = plot(xfit,Y+DELTA,'b--');
plot(xfit,Y-DELTA,'b--')

% Display the polynomial fit and the real roots.
approx_p = round(100*p)/100; % Round for display.
htitle = title(['\bf Fit:  '],...
    texlabel(polystr(approx_p)));
set(htitle,'Color','b')
approx_real_r = round(100*real_r)/100; % Round for display.
hxlabel = xlabel(['\bf Real Roots:  '],...
    num2str(approx_real_r));
set(hxlabel,'Color','b')

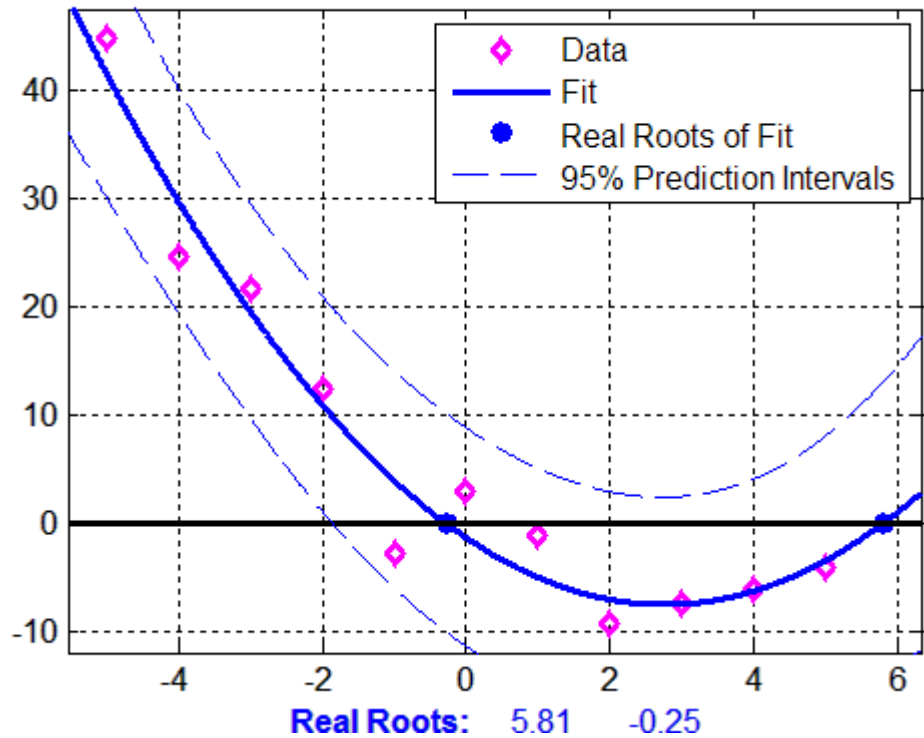
% Add a legend.
legend([hdata,hfit,hroots,hconf],...
    'Data','Fit','Real Roots of Fit',...

```

polyconf

'95% Prediction Intervals')

Fit: $0.81x^2 - 4.51x - 1.19$



See Also

[polyfit](#) | [polyval](#) | [polytool](#)

Purpose Interactive polynomial fitting

Syntax

```
polytool
polytool(x,y)
polytool(x,y,n)
polytool(x,y,n,alpha)
polytool(x,y,n,alpha,xname,yname)
h = polytool(...)
```

Description

`polytool`

`polytool(x,y)` fits a line to the vectors `x` and `y` and displays an interactive plot of the result in a graphical interface. You can use the interface to explore the effects of changing the parameters of the fit and to export fit results to the workspace.

`polytool(x,y,n)` initially fits a polynomial of degree `n`. The default is 1, which produces a linear fit.

`polytool(x,y,n,alpha)` initially plots $100(1 - \alpha)\%$ confidence intervals on the predicted values. The default is 0.05 which results in 95% confidence intervals.

`polytool(x,y,n,alpha,xname,yname)` labels the `x` and `y` values on the graphical interface using the strings `xname` and `yname`. Specify `n` and `alpha` as `[]` to use their default values.

`h = polytool(...)` outputs a vector of handles, `h`, to the line objects in the plot. The handles are returned in the degree: data, fit, lower bounds, upper bounds.

Examples **Interactive polynomial fitting**

This example shows how to start an interactive fitting session with `polytool`.

Generate data from a quadratic curve with added noise.

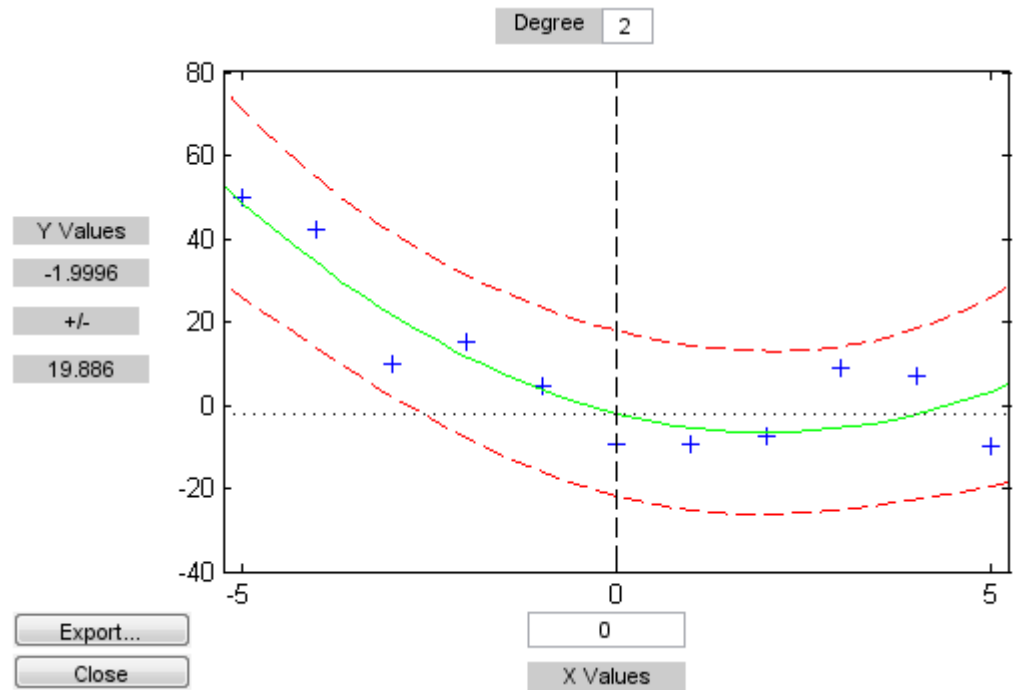
```
rng('default') % for reproducibility
x = -5:5;
```

polytool

```
y = x.^2 - 5*x - 3 + 5*randn(size(x));
```

Fit a quadratic (degree-2) model with 0.90 confidence intervals.

```
n = 2;  
alpha = 0.1;  
polytool(x,y,n,alpha)
```



See Also

[polyfit](#) | [polyval](#) | [polyconf](#) | [invpred](#)

Purpose

Posterior probabilities of components

Syntax

```
P = posterior(obj,X)
[P,nlogl] = posterior(obj,X)
```

Description

`P = posterior(obj,X)` returns the posterior probabilities of each of the k components in the Gaussian mixture distribution defined by `obj` for each observation in the data matrix `X`. `X` is n -by- d , where n is the number of observations and d is the dimension of the data. `obj` is an object created by `gmdistribution` or `fit`. `P` is n -by- k , with `P(I,J)` the probability of component `J` given observation `I`.

`posterior` treats NaN values as missing data. Rows of `X` with NaN values are excluded from the computation.

`[P,nlogl] = posterior(obj,X)` also returns `nlogl`, the negative log-likelihood of the data.

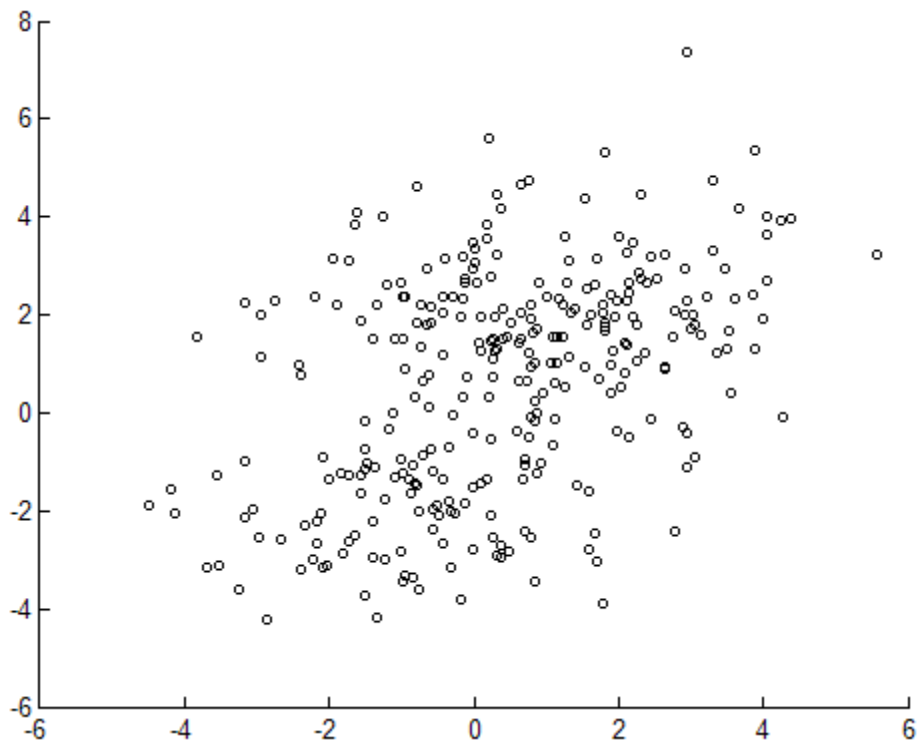
Examples

Generate data from a mixture of two bivariate Gaussian distributions using the `mvnrnd` function:

```
MU1 = [1 2];
SIGMA1 = [2 0; 0 .5];
MU2 = [-3 -5];
SIGMA2 = [1 0; 0 1];
X = [mvnrnd(MU1,SIGMA1,1000);mvnrnd(MU2,SIGMA2,1000)];
```

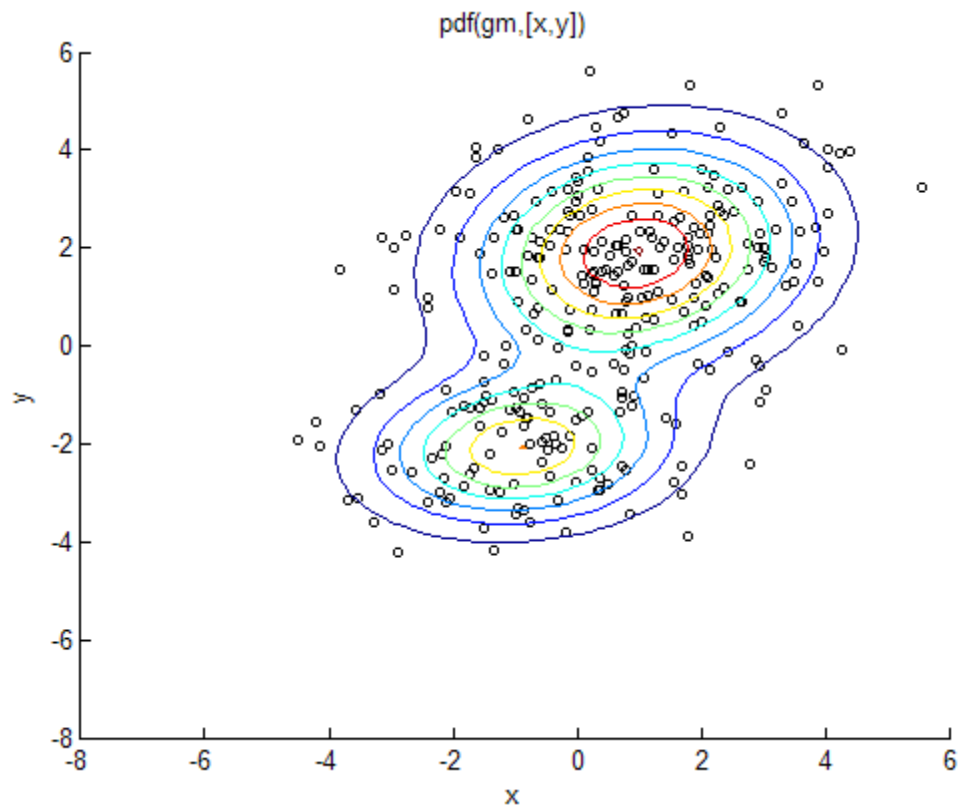
```
scatter(X(:,1),X(:,2),10,'.')
hold on
```

gmdistribution.posterior



Fit a two-component Gaussian mixture model:

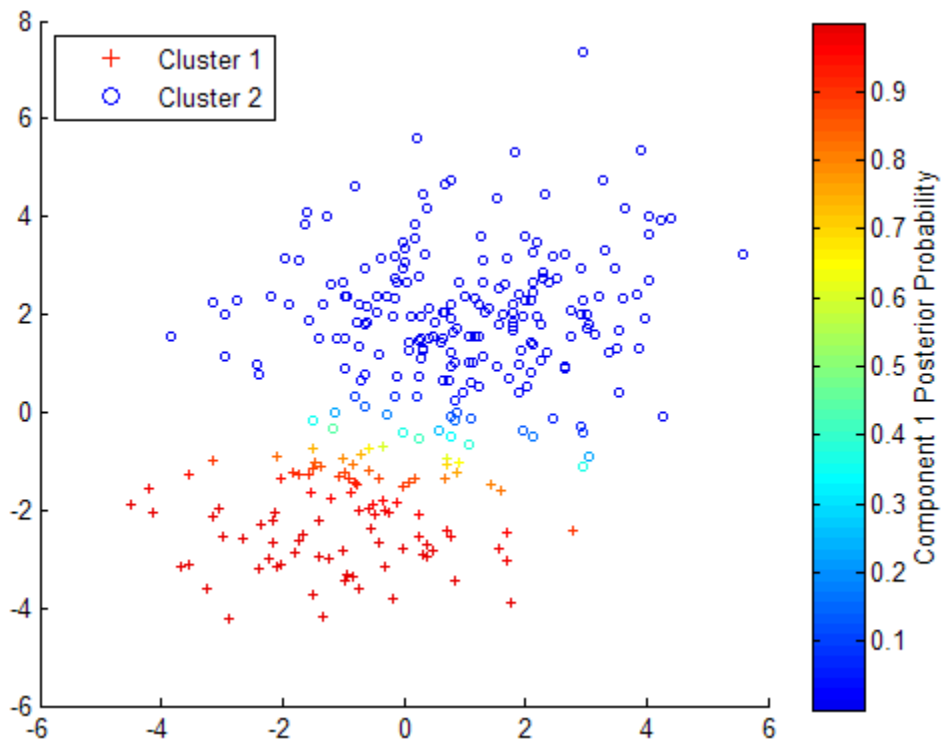
```
obj = gmdistribution.fit(X,2);  
h = ezcontour(@(x,y)pdf(obj,[x y]),[-8 6],[-8 6]);
```



Compute posterior probabilities of the components:

```
P = posterior(obj,X);  
  
delete(h)  
scatter(X(:,1),X(:,2),10,P(:,1),'.')  
hb = colorbar;  
ylabel(hb,'Component 1 Probability')
```

gmdistribution.posterior



See Also

`gmdistribution` | `fit` | `cluster` | `mahal`

Purpose

Compute posterior probability of each class for test data

Syntax

```
post = posterior(nb,test)
[post,cpre] = posterior(nb,test)
[post,cpre,logp] = posterior(nb,test)
[...] = posterior(..., 'HandleMissing',val)
```

Description

`post = posterior(nb,test)` returns the posterior probability of the observations in `test` according to the `NaiveBayes` object `nb`. `test` is a `N-by-nb.ndims` matrix, where `N` is the number of observations in the test data. Rows of `test` correspond to points, columns of `test` correspond to features. `post` is a `N-by-nb.nclasses` matrix containing the posterior probability of each observation for each class. `post(i,j)` is the posterior probability of point `I` belonging to class `j`. Classes are ordered the same as `nb.clevels`, i.e., column `j` of `post` corresponds to the `j`th class in `nb.clevels`. The posterior probabilities corresponding to any empty classes are `NaN`.

`[post,cpre] = posterior(nb,test)` returns `cpre`, an `N-by-1` vector, containing the class to which each row of `test` has been assigned. `cpre` has the same type as `nb.CLevels`.

`[post,cpre,logp] = posterior(nb,test)` returns `logp`, an `N-by-1` vector containing estimates of the log of the probability density function (PDF). `logp(i)` is the log of the PDF of point `i`. The PDF value of point `i` is the sum of $\text{Prob}(\text{point } I \mid \text{class } J) * \text{Pr}\{\text{class } J\}$ taken over all classes.

`[...] = posterior(..., 'HandleMissing',val)` specifies how `posterior` treats `NaN` (missing values). `val` can be one of the following:

NaiveBayes.posterior

'off' (default)	Observations with NaN in any of the columns are not classified into any class. The corresponding rows in <code>post</code> and <code>logp</code> are NaN. The corresponding rows in <code>cpre</code> are NaN (if <code>obj.clevels</code> is numeric or logical), empty strings (if <code>obj.clevels</code> is char or cell array of strings) or (if <code>obj.clevels</code> is categorical).
'on'	For observations having NaN in some (but not all) columns, <code>post</code> and <code>cpre</code> are computed using the columns with non-NaN values. Corresponding <code>logp</code> values are NaN.

See Also

NaiveBayes | fit | predict

Purpose	Percentiles of a data set
Syntax	$Y = \text{prctile}(X,p)$ $Y = \text{prctile}(X,p,\text{dim})$
Description	<p>$Y = \text{prctile}(X,p)$ returns percentiles of the values in a data vector or matrix X for the percentages p in the interval $[0,100]$.</p> <ul style="list-style-type: none">• If X is a vector, then Y is a scalar or a vector with the same length as the number of percentiles required ($\text{length}(p)$). $Y(i)$ contains the $p(i)$ percentile.• If X is a matrix, then Y is a row vector or a matrix, where the number of rows of Y is equal to the number of percentiles required ($\text{length}(p)$). The ith row of Y contains the $p(i)$ percentiles of each column of X.• For multidimensional arrays, prctile operates along the first nonsingleton dimension of X. <p>$Y = \text{prctile}(X,p,\text{dim})$ returns percentiles along dimension dim.</p>
Input Arguments	<p>X - Input data vector array</p> <p>Input data, specified as a vector or array.</p> <p>Data Types double single</p> <p>p - Percentages scalar vector</p> <p>Percentages for which to compute percentiles, returned as a scalar or vector of scalars from 0 to 100.</p> <p>Example: 25</p> <p>Example: [25, 50, 75]</p>

Data Types

double | single

dim - Dimension

1 (default) | positive integer

Dimension along which the percentiles of X are required, specified as a positive integer. For example, for a matrix X , when $\text{dim} = 1$, `prctile` returns the quantile(s) of the columns of X and when $\text{dim} = 2$, `prctile` returns the quantile(s) of the rows of X . For a multidimensional array X , the length of the dim th dimension of Y is equal to the length of p .

Data Types

double

Output Arguments

Y - Percentiles

scalar | array

Percentiles of a data vector or array, specified as a scalar or array for one or more percentage values.

- If X is a vector, then Y is a scalar or a vector with the same length as the number of percentiles required (`length(p)`). $Y(i)$ contains the $p(i)$ th percentile.
- If X is a matrix, then Y is a vector or a matrix with the length of the dim th dimension equal to the number percentiles required (`length(p)`). When $\text{dim} = 1$, for example, the i th row of Y contains the $p(i)$ th percentiles of columns of X .
- If X is an array of dimension d , then Y is an array with the length of the dim th dimension equal to the number of percentiles required (`length(p)`).

Definitions

Multidimensional Array

A *multidimensional array* is an array with more than two dimensions. For example, if X is a 1-by-3-by-4 array, then X is a 3-D array.

Nonsingleton Dimension

A *first nonsingleton dimension* is the first dimension of an array whose size is not equal to 1. For example, if X is a 1-by-2-by-3-by-4 array, then the second dimension is the first nonsingleton dimension of X .

Linear Interpolation

Linear interpolation uses linear polynomials to find $y_i = f(x_i)$, the values of the underlying function $Y = f(X)$ at the points in the vector or array x . Given the data points (x_1, y_1) and (x_2, y_2) , where $y_1 = f(x_1)$ and $y_2 = f(x_2)$, linear interpolation finds $y = f(x)$ for a given x between x_1 and x_2 as follows:

$$y = f(x) = y_1 + \frac{(x - x_1)}{(x_2 - x_1)}(y_2 - y_1).$$

Similarly, if the $100(1.5/n)$ th percentile is $y_{1.5/n}$ and the $100(2.5/n)$ th percentile is $y_{2.5/n}$, then linear interpolation finds the $100(2.3/n)$ th percentile, $y_{2.3/n}$ as:

$$\frac{y_{2.3}}{n} = \frac{y_{1.5}}{n} + \frac{\left(\frac{2.3}{n} - \frac{1.5}{n}\right)}{\left(\frac{2.5}{n} - \frac{1.5}{n}\right)} \left(\frac{y_{2.5}}{n} - \frac{y_{1.5}}{n}\right).$$

Algorithms

For an n -element vector X , `prctile` returns percentiles as follows:

- 1 The sorted values in X are taken as the $100(0.5/n)$ th, $100(1.5/n)$ th, ..., $100([n - 0.5]/n)$ th percentiles. For example:
 - For a data vector of five elements such as $\{6, 3, 2, 10, 1\}$, the sorted elements $\{1, 2, 3, 6, 10\}$ respectively correspond to the 10th, 30th, 50th, 70th, and 90th percentiles.
 - For a data vector of six elements such as $\{6, 3, 2, 10, 8, 1\}$, the sorted elements $\{1, 2, 3, 6, 8, 10\}$ respectively correspond to the

(50/6)th, (150/6)th, (250/6)th, (350/6)th, (450/6)th, and (550/6)th percentiles.

- 2** `prctile` uses linear interpolation to compute percentiles for percentages between $100(0.5/n)$ and $100([n - 0.5]/n)$.
- 3** `prctile` assigns the minimum or maximum values in `X` to the percentiles corresponding to the percentages outside that range.

`prctile` treats NaNs as missing values and removes them.

Examples

Percentiles of a Data Vector

Generate a data set of size 10.

```
rng('default'); % for reproducibility
x = normrnd(5,2,1,10)
```

```
x =
    6.0753    8.6678    0.4823    6.7243    5.6375    2.3846    4.1328
```

Calculate the 42nd percentile.

```
Y = prctile(X,42)
```

```
Y =
    5.6709
```

Percentiles of a Data Matrix

Calculate the percentiles along the columns and rows of a data matrix for specified percentages.

Generate a 5-by-5 data matrix.

```
X = (1:5)'*(2:6)
```

```
X =
```

2	3	4	5	6
4	6	8	10	12
6	9	12	15	18
8	12	16	20	24
10	15	20	25	30

Calculate the 25th, 50th, and 75th percentiles along the columns of X.

```
Y = prctile(X,[25 50 75],1)
```

```
Y =
    3.5000    5.2500    7.0000    8.7500   10.5000
    6.0000    9.0000   12.0000   15.0000   18.0000
    8.5000   12.7500   17.0000   21.2500   25.5000
```

The rows of Y correspond to the percentiles of columns of X. For example, the 25th, 50th, and 75th percentiles of the third column of X with elements (4, 8, 12, 16, 20) are 7, 12, and 17, respectively. `Y = prctile(X,[25 50 75])` returns the same percentile matrix.

Calculate the 25th, 50th, and 75th percentiles along the rows of X.

```
Y = prctile(X,[25 50 75],2)
```

```
Y =
    2.7500    4.0000    5.2500
    5.5000    8.0000   10.5000
    8.2500   12.0000   15.7500
   11.0000   16.0000   21.0000
   13.7500   20.0000   26.2500
```

The rows of Y correspond to the percentiles of rows of X. For example, the 25th, 50th, and 75th percentiles of the first row of X with elements (2, 3, 4, 5, 6) are 2.75, 4, and 5.25, respectively.

See Also

[quantile](#) | [median](#) | [iqr](#)

prctile

Concepts

- “Quantiles and Percentiles” on page 3-7

Purpose	Predict k -nearest neighbor classification
Syntax	<pre>label = predict(md1,Xnew) [label,score] = predict(md1,Xnew) [label,score,cost] = predict(md1,Xnew)</pre>
Description	<p><code>label = predict(md1,Xnew)</code> returns a vector of predicted class labels for a matrix <code>Xnew</code>, based on <code>md1</code>, a <code>ClassificationKNN</code> model.</p> <p><code>[label,score] = predict(md1,Xnew)</code> returns a matrix of scores, indicating the likelihood that a label comes from a particular class.</p> <p><code>[label,score,cost] = predict(md1,Xnew)</code> returns a matrix of costs; <code>label</code> is the vector of minimal costs for each row of <code>cost</code></p>
Input Arguments	<p>md1</p> <p>k-nearest neighbor classifier, created by <code>ClassificationKNN.fit</code>.</p> <p>Xnew</p> <p>Points at which <code>md1</code> predicts classifications. Each row of <code>Xnew</code> is one point. The number of columns in <code>Xnew</code> must equal the number of predictors in <code>md1</code>.</p>
Output Arguments	<p>label</p> <p>Predicted class labels for the points in <code>Xnew</code>, a vector with length equal to the number of rows of <code>Xnew</code>. The label is the class with minimal expected cost. See “Predicted Class Label” on page 20-1830.</p> <p>score</p> <p>Numeric matrix of size N-by-K, where N is the number of observations (rows) in <code>Xnew</code>, and K is the number of classes (in <code>md1.ClassNames</code>). <code>score(i,j)</code> is the posterior probability that row <code>i</code> of <code>Xnew</code> is of class <code>j</code>. See “Posterior Probability” on page 20-1830.</p> <p>cost</p>

ClassificationKNN.predict

Matrix of expected costs of size N-by-K, where N is the number of observations (rows) in X_{new} , and K is the number of classes (in mdl.ClassNames). $\text{cost}(i, j)$ is the cost of classifying row i of X as class j . See “Expected Cost” on page 20-1831.

Definitions

Predicted Class Label

`predict` classifies so as to minimize the expected classification cost:

$$\hat{y} = \arg \min_{y=1, \dots, K} \sum_{k=1}^K \hat{P}(k | x) C(y | k),$$

where

- \hat{y} is the predicted classification.
- K is the number of classes.
- $\hat{P}(k | x)$ is the posterior probability of class k for observation x .
- $C(y | k)$ is the cost of classifying an observation as y when its true class is k .

Posterior Probability

For a vector (single query point) X_{new} and model mdl , let:

- K be the number of nearest neighbors used in prediction, mdl.NumNeighbors
- $\text{nbd}(\text{mdl}, X_{\text{new}})$ be the K nearest neighbors to X_{new} in mdl.X
- $Y(\text{nbd})$ be the classifications of the points in $\text{nbd}(\text{mdl}, X_{\text{new}})$, namely $\text{mdl.Y}(\text{nbd})$
- $W(\text{nbd})$ be the weights of the points in $\text{nbd}(\text{mdl}, X_{\text{new}})$
- prior be the priors of the classes in mdl.Y

If there is a vector of prior probabilities, then the observation weights W are normalized by class to sum to the priors. This might involve a calculation for the point X_{new} , because weights can depend on the distance from X_{new} to the points in mdl.X .

The posterior probability $p(j | X_{\text{new}})$ is

$$p(j | X_{\text{new}}) = \frac{\sum_{i \in \text{nd}} W(i) 1_{Y(X(i)=j)}}{\sum_{i \in \text{nd}} W(i)}.$$

Here, $1_{Y(X(i)=j)}$ means 1 when $\text{mdl.Y}(i) = j$, and 0 otherwise.

True Misclassification Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation.

You can set the true misclassification cost per class in the `Cost` name-value pair when you run `ClassificationKNN.fit`. `Cost(i,j)` is the cost of classifying an observation into class j if its true class is i . By default, `Cost(i,j)=1` if $i \neq j$, and `Cost(i,j)=0` if $i=j$. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

Expected Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation. The third output of `predict` is the expected misclassification cost per observation.

Suppose you have `Nobs` observations that you want to classify with a trained classifier `mdl`. Suppose you have `K` classes. You place the observations into a matrix `Xnew` with one observation per row. The command

```
[label,score,cost] = predict(mdl,Xnew)
```

ClassificationKNN.predict

returns, among other outputs, a `cost` matrix of size `Nobs-by-K`. Each row of the `cost` matrix contains the expected (average) cost of classifying the observation into each of the `K` classes. `cost(n,k)` is

$$\sum_{i=1}^K \hat{P}(i | X_{new}(n)) C(k | i),$$

where

- K is the number of classes.
- $\hat{P}(i | X_{new}(n))$ is the posterior probability of class i for observation $X_{new}(n)$.
- $C(k | i)$ is the true misclassification cost of classifying an observation as k when its true class is i .

Examples

KNN Classification Predictions

Construct a k -nearest neighbor classifier for the Fisher iris data, where $k = 5$. Evaluate some model predictions on new data.

Load the data.

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',5);
```

Predict the classifications for flowers with minimum, mean, and maximum characteristics.

```
Xnew = [min(X);mean(X);max(X)];
[label,score,cost] = predict(mdl,Xnew)
```

```
label =
  'setosa'
  'versicolor'
  'virginica'

score =
  1    0    0
  0    1    0
  0    0    1

cost =
  0    1    1
  1    0    1
  1    1    0
```

The classifications have binary values for the score and cost matrices, meaning all five nearest neighbors of each of the three points have identical classifications.

See Also [ClassificationKNN |](#)

Related Examples

- “Predict Classification Based on a KNN Classifier” on page 13-27

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

CompactClassificationDiscriminant.predict

Purpose	Predict classification
Syntax	<pre>label = predict(obj,X) [label,score] = predict(obj,X) [label,score,cost] = predict(obj,X)</pre>
Description	<p><code>label = predict(obj,X)</code> returns a vector of predicted class labels for a matrix <code>X</code>, based on <code>obj</code>, a trained full or compact classifier.</p> <p><code>[label,score] = predict(obj,X)</code> returns a matrix of scores (posterior probabilities).</p> <p><code>[label,score,cost] = predict(obj,X)</code> returns a matrix of costs; <code>label</code> is the vector of minimal costs for each row of <code>cost</code>.</p>
Input Arguments	<p>obj</p> <p>Discriminant analysis classifier of class <code>ClassificationDiscriminant</code> or <code>CompactClassificationDiscriminant</code>, typically constructed with <code>ClassificationDiscriminant.fit</code>.</p> <p>X</p> <p>Matrix where each row represents an observation, and each column represents a predictor. The number of columns in <code>X</code> must equal the number of predictors in <code>obj</code>.</p>
Output Arguments	<p>label</p> <p>Vector of class labels of the same type as the response data used in training <code>obj</code>. Each entry of <code>labels</code> corresponds to a predicted class label for the corresponding row of <code>X</code>; see “Predicted Class Label” on page 20-1836.</p> <p>score</p> <p>Numeric matrix of size N-by-K, where N is the number of observations (rows) in <code>X</code>, and K is the number of classes (in</p>

obj.ClassNames). score(i, j) is the posterior probability that row i of X is of class j; see "Posterior Probability" on page 20-1835.

cost

Matrix of expected costs of size N-by-K. cost(i, j) is the cost of classifying row i of X as class j. See "Cost" on page 20-1836.

Definitions

Posterior Probability

The posterior probability that a point z belongs to class j is the product of the prior probability and the multivariate normal density. The density function of the multivariate normal with mean μ_j and covariance Σ_j at a point z is

$$P(x | k) = \frac{1}{(2\pi |\Sigma_k|)^{1/2}} \exp\left(-\frac{1}{2}(x - \mu_k)^T \Sigma_k^{-1} (x - \mu_k)\right),$$

where $|\Sigma_k|$ is the determinant of Σ_k , and Σ_k^{-1} is the inverse matrix.

Let $P(k)$ represent the prior probability of class k . Then the posterior probability that an observation x is of class k is

$$\hat{P}(k | x) = \frac{P(x | k)P(k)}{P(x)},$$

where $P(x)$ is a normalization constant, the sum over k of $P(x | k)P(k)$.

Prior Probability

The prior probability is one of three choices:

- 'uniform' — The prior probability of class k is one over the total number of classes.
- 'empirical' — The prior probability of class k is the number of training samples of class k divided by the total number of training samples.

CompactClassificationDiscriminant.predict

- Custom — The prior probability of class k is the k th element of the prior vector. See `ClassificationDiscriminant.fit`.

After creating a classifier `obj`, you can set the prior by dot addressing:

```
obj.Prior = v;
```

where v is a vector of positive elements representing the frequency with which each element occurs. You do not need to retrain the classifier when you set a new prior.

Cost

The matrix of expected costs per observation is defined in “Cost” on page 12-8.

Predicted Class Label

`predict` classifies so as to minimize the expected classification cost:

$$\hat{y} = \arg \min_{y=1,\dots,K} \sum_{k=1}^K \hat{P}(k|x)C(y|k),$$

where

- \hat{y} is the predicted classification.
- K is the number of classes.
- $\hat{P}(k|x)$ is the posterior probability of class k for observation x .
- $C(y|k)$ is the cost of classifying an observation as y when its true class is k .

Examples

Examine predictions for a few rows in the Fisher iris data:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
X = meas(99:102,:); % take four rows
```

CompactClassificationDiscriminant.predict

```
[label score cost] = predict(obj,X)
```

```
label =
```

```
    'versicolor'
```

```
    'versicolor'
```

```
    'virginica'
```

```
    'virginica'
```

```
score =
```

```
    0.0000    1.0000    0.0000
```

```
    0.0000    0.9999    0.0001
```

```
    0.0000    0.0000    1.0000
```

```
    0.0000    0.0011    0.9989
```

```
cost =
```

```
    1.0000    0.0000    1.0000
```

```
    1.0000    0.0001    0.9999
```

```
    1.0000    1.0000    0.0000
```

```
    1.0000    0.9989    0.0011
```

See Also

[ClassificationDiscriminant](#) | [ClassificationDiscriminant.fit](#) | [edge](#) | [loss](#) | [margin](#)

How To

- “Discriminant Analysis” on page 12-3

CompactClassificationEnsemble.predict

Purpose Predict classification

Syntax
`labels = predict(ens,X)`
`[labels,score] = predict(ens,X)`
`[labels,...] = predict(ens,X,Name,Value)`

Description `labels = predict(ens,X)` returns a vector of predicted class labels for a matrix `X`, based on `ens`, a trained full or compact classification ensemble.

`[labels,score] = predict(ens,X)` also returns scores for all classes.

`[labels,...] = predict(ens,X,Name,Value)` predicts classifications with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A classification ensemble created by `fitensemble`, or a compact classification ensemble created by `compact`.

X

A matrix where each row represents an observation, and each column represents a predictor. The number of columns in `X` must equal the number of predictors in `ens`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

Indices of weak learners `predict` uses for computation of responses, a numeric vector.

Default: $1:T$, where T is the number of weak learners in `ens`

UseObsForLearner

A logical matrix of size N -by- T , where:

- N is the number of rows of X .
- T is the number of weak learners in `ens`.

When `UseObsForLearner(i, j)` is `true`, learner j is used in predicting the class of row i of X .

Default: `true(N, T)`

Output Arguments

labels

Vector of classification labels. `labels` has the same data type as the labels used in training `ens`.

score

A matrix with one row per observation and one column per class. For each observation and each class, the score generated by each tree is the probability of this observation originating from this class computed as the fraction of observations of this class in a tree leaf. `predict` averages these scores over all trees in the ensemble.

Definitions

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

CompactClassificationEnsemble.predict

Examples

Train a boosting ensemble for the ionosphere data, and predict the classification of the mean of the data:

```
load ionosphere;
ada = fitensemble(X,Y,'AdaBoostM1',100,'tree');
Xbar = mean(X);
[ypredict score] = predict(ada,Xbar)
```

```
ypredict =
    'g'
```

```
score =
    -2.9460    2.9460
```

See Also

[margin](#) | [edge](#) | [loss](#)

Purpose

Predict classification

Syntax

```
label = predict(tree,X)
[label,score] = predict(tree,X)
[label,score,node] = predict(tree,X)
[label,score,node,cnum] = predict(tree,X)
[label,...] = predict(tree,X,Name,Value)
```

Description

`label = predict(tree,X)` returns a vector of predicted class labels for a matrix `X`, based on `tree`, a trained full or compact classification tree.

`[label,score] = predict(tree,X)` returns a matrix of scores, indicating the likelihood that a label comes from a particular class.

`[label,score,node] = predict(tree,X)` returns a vector of predicted node numbers for the classification, based on `tree`.

`[label,score,node,cnum] = predict(tree,X)` returns a vector of predicted class number for the classification, based on `tree`.

`[label,...] = predict(tree,X,Name,Value)` returns labels with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

tree

A classification tree created by `ClassificationTree.fit`, or a compact classification tree created by `compact`.

X

A matrix where each row represents an observation, and each column represents a predictor. The number of columns in `X` must equal the number of predictors in `tree`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can

CompactClassificationTree.predict

specify several name and value pair arguments in any order as Name1, Value1, . . . , NameN, ValueN.

subtrees

Numeric vector of pruning levels, with 0 representing the full, unpruned tree. To use the `subtrees` name-value pair, `tree` must include a pruning sequence as created by the `ClassificationTree.fit` or `prune` methods. If `subtrees` has `T` elements, and `X` has `N` rows, then `labels` is an `N`-by-`T` matrix. The `i`th column of `labels` contains the fitted values produced by the `subtrees(I)` subtree. Similarly, `score` is an `N`-by-`K`-by-`T` array, and `node` and `cnum` are `N`-by-`T` matrices. `subtrees` must be sorted in ascending order. (To compute fitted values for a tree that is not part of the optimal pruning sequence, first use `prune` to prune the tree.)

Default: 0

Output Arguments

label

Vector of class labels of the same type as the response data used in training `tree`. Each entry of `label` corresponds to the class with minimal expected cost for the corresponding row of `X`. See “Predicted Class Label” on page 20-1843.

score

Numeric matrix of size `N`-by-`K`, where `N` is the number of observations (rows) in `X`, and `K` is the number of classes (in `tree.ClassNames`). `score(i, j)` is the posterior probability that row `i` of `X` is of class `j`.

node

Numeric vector of node numbers for the predicted classes. Each entry corresponds to the predicted node in `tree` for the corresponding row of `X`.

cnum

Numeric vector of class numbers corresponding to the predicted labels. Each entry of `cnum` corresponds to a predicted class number for the corresponding row of `X`.

Definitions

Predicted Class Label

`predict` classifies so as to minimize the expected classification cost:

$$\hat{y} = \arg \min_{y=1,\dots,K} \sum_{k=1}^K \hat{P}(k | x) C(y | k),$$

where

- \hat{y} is the predicted classification.
- K is the number of classes.
- $\hat{P}(k | x)$ is the posterior probability of class k for observation x .
- $C(y | k)$ is the cost of classifying an observation as y when its true class is k .

Score (tree)

For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

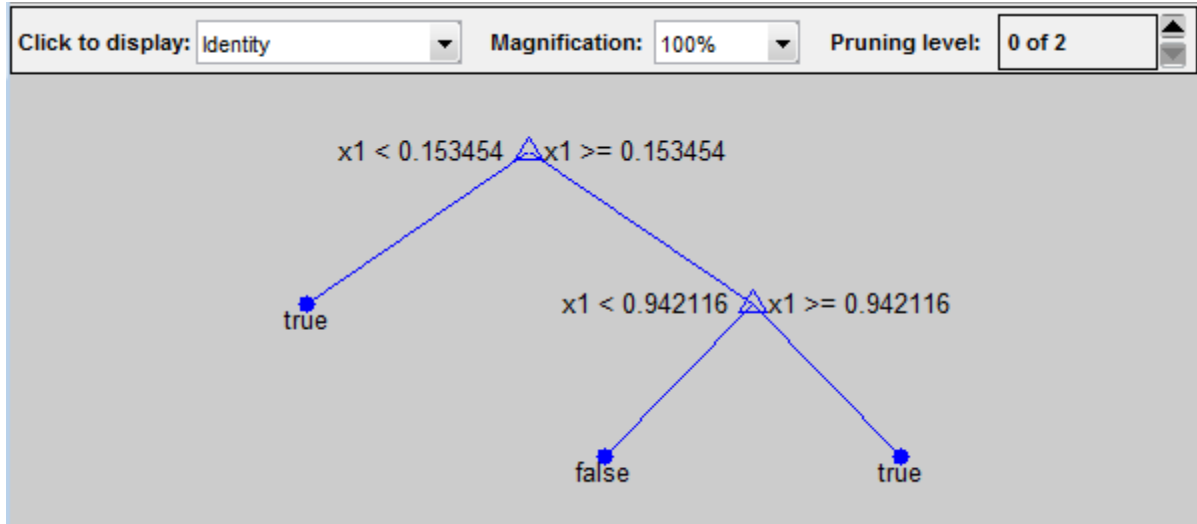
1

Generate 100 random points and classify them:

```
rng(0, 'twister') % for reproducibility
X = rand(100,1);
```

CompactClassificationTree.predict

```
Y = (abs(X - .55) > .4);  
tree = ClassificationTree.fit(X,Y);  
view(tree,'mode','graph')
```

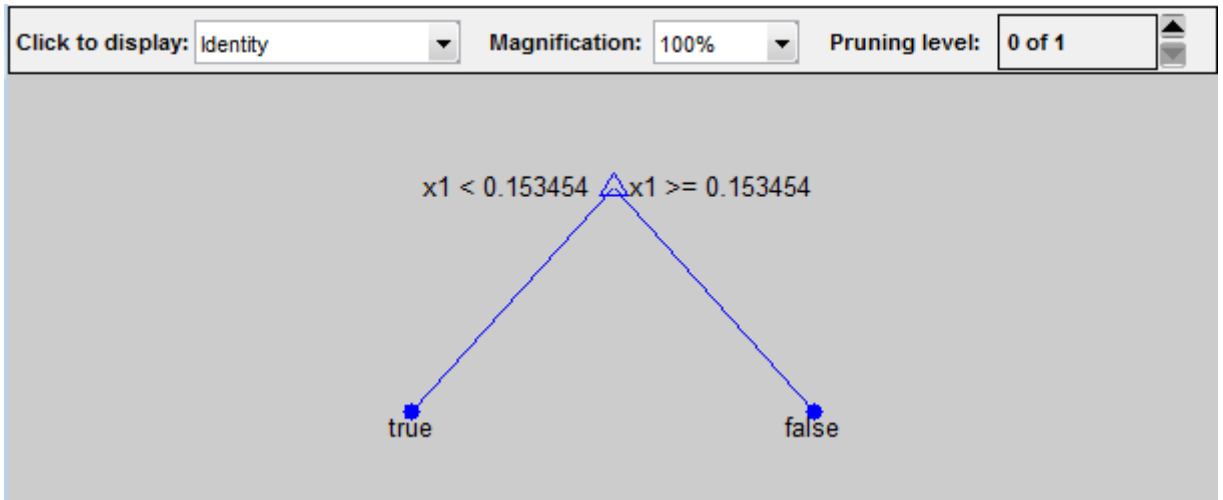


2

Prune the tree:

```
tree1 = prune(tree,'level',1);  
view(tree1,'mode','graph')
```

CompactClassificationTree.predict



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
0.9059    0.0941    0.8147  
0.9059    0.0941    0.9058  
0        1.0000    0.1270  
0.9059    0.0941    0.9134  
0.9059    0.0941    0.6324  
0        1.0000    0.0975  
0.9059    0.0941    0.2785
```

CompactClassificationTree.predict

0.9059	0.0941	0.5469
0.9059	0.0941	0.9575
0.9059	0.0941	0.9649

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range $(.95, 1)$ instead of the expected 5 observations.

True Misclassification Cost

There are two costs associated with classification: the true misclassification cost per class, and the expected misclassification cost per observation.

You can set the true misclassification cost per class in the `Cost` name-value pair when you create the classifier using the `ClassificationTree.fit` method. $\text{Cost}(i, j)$ is the cost of classifying an observation into class j if its true class is i . By default, $\text{Cost}(i, j)=1$ if $i \neq j$, and $\text{Cost}(i, j)=0$ if $i=j$. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

Expected Cost

There are two costs associated with classification: the true misclassification cost per class, and the expected misclassification cost per observation.

Suppose you have N observations that you want to classify with a trained classifier. Suppose you have K classes. You place the observations into a matrix X_{new} with one observation per row.

The expected cost matrix CE has size N -by- K . Each row of CE contains the expected (average) cost of classifying the observation into each of the K classes. $CE(n, k)$ is

$$\sum_{i=1}^K \hat{P}(i | X_{new}(n)) C(k | i),$$

where

- K is the number of classes.
- $\hat{P}(i | X_{new}(n))$ is the posterior probability of class i for observation $X_{new}(n)$.
- $C(k | i)$ is the true misclassification cost of classifying an observation as k when its true class is i .

Predictive Measure of Association

The predictive measure of association between the optimal split on variable i and a surrogate split on variable j is:

$$\lambda_{i,j} = \frac{\min(P_L, P_R) - (1 - P_{L_i L_j} - P_{R_i R_j})}{\min(P_L, P_R)}.$$

Here

- P_L and P_R are the node probabilities for the optimal split of node i into Left and Right nodes respectively.
- $P_{L_i L_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Left.
- $P_{R_i R_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Right.

Clearly, $\lambda_{i,j}$ lies from $-\infty$ to 1. Variable j is a worthwhile surrogate split for variable i if $\lambda_{i,j} > 0$.

CompactClassificationTree.predict

Examples

Examine predictions for a few rows in the Fisher iris data:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
X = meas(99:102,:); % take four rows
[label score node cnum] = predict(tree,X)
```

```
label =
    'versicolor'
    'versicolor'
    'virginica'
    'virginica'
```

```
score =
    0    1.0000         0
    0    1.0000         0
    0    0.0217    0.9783
    0    0.0217    0.9783
```

```
node =
    8
    8
    5
    5
```

```
cnum =
    2
    2
    3
    3
```

Examine predictions from pruned trees for the Fisher iris model:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
X = meas(99:102,:); % taking four rows
```

CompactClassificationTree.predict

```
[label score node cnum] = predict(tree,X,'subtrees',[2 3 4])
```

```
label =
```

```
    'versicolor'    'versicolor'    'setosa'  
    'versicolor'    'versicolor'    'setosa'  
    'virginica'     'versicolor'    'setosa'  
    'virginica'     'versicolor'    'setosa'
```

```
score(:, :, 1) =
```

```
    0    0.9074    0.0926  
    0    0.9074    0.0926  
    0    0.0217    0.9783  
    0    0.0217    0.9783
```

```
score(:, :, 2) =
```

```
    0    0.5000    0.5000  
    0    0.5000    0.5000  
    0    0.5000    0.5000  
    0    0.5000    0.5000
```

```
score(:, :, 3) =
```

```
    0.3333    0.3333    0.3333  
    0.3333    0.3333    0.3333  
    0.3333    0.3333    0.3333  
    0.3333    0.3333    0.3333
```

```
node =
```

```
    4    3    1  
    4    3    1  
    5    3    1  
    5    3    1
```

```
cnum =
```

```
    2    2    1  
    2    2    1  
    3    2    1  
    3    2    1
```

CompactClassificationTree.predict

Algorithms

`predict` generates predictions by following the branches of `tree` until it reaches a leaf node or a missing value. If `predict` reaches a leaf node, it returns the classification of that node.

If `predict` reaches a node with a missing value for a predictor, its behavior depends on the setting of the `Surrogate` name-value pair when `ClassificationTree.fit` constructs `tree`.

- **Surrogate = 'off'** (default) — `predict` returns the label with the largest number of training samples that reach the node.
- **Surrogate = 'on'** — `predict` uses the best surrogate split at the node. If all surrogate split variables with positive *predictive measure of association* are missing, `predict` returns the label with the largest number of training samples that reach the node. For a definition, see “Predictive Measure of Association” on page 20-1847.

See Also

`ClassificationTree.fit` | `compact` | `prune` | `loss` | `edge` | `margin`

Purpose

Predict response of ensemble

Syntax

```
Yfit = predict(ens,Xdata)
Yfit = predict(ens,Xdata,Name,Value)
```

Description

`Yfit = predict(ens,Xdata)` returns predicted responses to the data in `Xdata`, based on the `ens` regression ensemble model.

`Yfit = predict(ens,Xdata,Name,Value)` predicts with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments**ens**

Regression ensemble created by `fitensemble`, or by the compact method.

Xdata

Numeric array with the same number of columns as the array used for creating `ens`. Each row of `Xdata` corresponds to one data point, and each column corresponds to one predictor.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

Indices of weak learners in the ensemble ranging from 1 to `ens.NTrained`. `oobEdge` uses only these learners for calculating loss.

Default: 1:NTrained

UseObsForLearner

CompactRegressionEnsemble.predict

A logical matrix of size N-by-NTrained, where N is the number of observations in `ens.X`, and NTrained is the number of weak learners. When `UseObsForLearner(I,J)` is true, `predict` uses learner J in predicting observation I.

Default: `true(N,NTrained)`

Output Arguments

Yfit

A numeric column vector with the same number of rows as `Xdata`. Each row of `Yfit` gives the predicted response to the corresponding row of `Xdata`, based on the `ens` regression model.

Examples

Find the predicted mileage for a four-cylinder car, with 200 cubic inch engine displacement, 150 horsepower, weighing 3000 lbs, based on the `carsmall` data:

```
load carsmall
X = [Cylinders Displacement Horsepower Weight];
rens = fitensemble(X,MPG,'LSBoost',100,'Tree');
Mileage = predict(rens,[4 200 150 3000])
```

```
Mileage =
    20.4982
```

See Also

`loss` | `fitensemble`

Purpose

Predict response of regression tree

Syntax

```
Yfit = predict(tree,Xdata)
[Yfit,node] = predict(tree,Xdata)
[Yfit,node] = predict(tree,Xdata,Name,Value)
```

Description

`Yfit = predict(tree,Xdata)` returns predicted responses to the data in `Xdata`, based on the tree regression tree.

`[Yfit,node] = predict(tree,Xdata)` returns the predicted node numbers of tree in response to `Xdata`.

`[Yfit,node] = predict(tree,Xdata,Name,Value)` predicts response with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

tree

Regression tree created by `RegressionTree.fit`, or by the `compact` method.

Xdata

Numeric array with the same number of columns as the array used for creating `tree`. Each row of `Xdata` corresponds to one data point, and each column corresponds to one predictor.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

subtrees

Numeric vector of pruning levels, with 0 representing the full, unpruned tree. To use the `subtrees` name-value pair, `tree` must include a pruning sequence as created by the

CompactRegressionTree.predict

RegressionTree.fit or prune methods. If subtrees has T elements, and X has N rows, then Yfit is an N-by-T matrix. The ith column of Yfit contains the fitted values produced by the subtrees(I) subtree. Similarly, node is an N-by-T matrix. subtrees must be sorted in ascending order. (To compute fitted values for a tree that is not part of the optimal pruning sequence, first use prune to prune the tree.)

Default: 0

Output Arguments

Yfit

A numeric column vector with the same number of rows as Xdata. Each row of Yfit gives the predicted response to the corresponding row of Xdata, based on the tree regression model.

node

Numeric vector of node numbers for the predictions. Each entry corresponds to the predicted leaf node in tree for the corresponding row of Xdata.

Examples

Find the predicted mileage for a car with 200 cubic inch engine displacement, 150 horsepower, weighing 3000 lbs, based on the carsmall data:

```
load carsmall
X = [Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
Mileage = predict(tree,[200 150 3000])
```

```
Mileage =
    21.9375
```

See Also

RegressionTree.fit | compact | loss

Purpose

Predict response

Syntax

```
YFIT = predict(B,X)
[YFIT,stdevs] = predict(B,X)
[YFIT,scores] = predict(B,X)
[YFIT,scores,stdevs] = predict(B,X)
Y = predict(B,X,'param1',val1,'param2',val2,...)
```

Description

`YFIT = predict(B,X)` computes the predicted response of the trained ensemble `B` for predictors `X`. By default, `predict` takes a democratic (nonweighted) average vote from all trees in the ensemble. In `X`, rows represent observations and columns represent variables. `YFIT` is a cell array of strings for classification and a numeric array for regression.

For regression, `[YFIT,stdevs] = predict(B,X)` also returns standard deviations of the computed responses over the ensemble of the grown trees.

For classification, `[YFIT,scores] = predict(B,X)` returns scores for all classes. `scores` is a matrix with one row per observation and one column per class. For each observation and each class, the score generated by each tree is the probability of this observation originating from this class computed as the fraction of observations of this class in a tree leaf. `predict` averages these scores over all trees in the ensemble.

`[YFIT,scores,stdevs] = predict(B,X)` also returns standard deviations of the computed scores for classification. `stdevs` is a matrix with one row per observation and one column per class, with standard deviations taken over the ensemble of the grown trees.

`Y = predict(B,X,'param1',val1,'param2',val2,...)` specifies optional parameter name/value pairs:

CompactTreeBagger.predict

'trees'	Array of tree indices to use for computation of responses. Default is 'all'.
'treeweights'	Array of NTrees weights for weighting votes from the specified trees.
'useifort'	Logical matrix of size Nobs-by-NTrees indicating which trees to use to make predictions for each observation. By default all trees are used for all observations.

See Also

`classregtree.eval` | `TreeBagger.predict`

Purpose

Predict response of generalized linear regression model

Syntax

```
ypred = predict mdl, Xnew
[ypred, yci] = predict mdl, Xnew
[ypred, yci] = predict mdl, Xnew, Name, Value
```

Description

`ypred = predict mdl, Xnew` returns the predicted response of the `mdl` generalized linear regression model to the points in `Xnew`.

`[ypred, yci] = predict mdl, Xnew` returns confidence intervals for the true mean responses.

`[ypred, yci] = predict mdl, Xnew, Name, Value` predicts responses with additional options specified by one or more `Name, Value` pair arguments.

Tips

- For predictions with added noise, use `random`.
- For a syntax that can be easier to use with models created from dataset arrays, try `feval`.

Input Arguments

mdl

Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

Xnew

Points at which `mdl` predicts responses.

- If `Xnew` is a dataset array, it must contain the predictor names in `mdl`.
- If `Xnew` is a numeric matrix, it must have the same number of variables (columns) as was used to create `mdl`. Furthermore, all variables used in creating `mdl` must be numeric.

GeneralizedLinearModel.predict

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

alpha

Positive scalar from 0 to 1. Confidence level of `yci` is $100(1 - \text{alpha})\%$.

Default: 0.05, meaning a 95% confidence interval.

BinomialSize

Value of the binomial n parameter for each row in the training data. `BinomialSize` can be a vector the same length as `Xnew`, or a scalar that applies to each row. The default value 1 produces `ypred` values that are predicted proportions. Use `BinomialSize` only if `mdl` is fit to a binomial distribution.

Default: 1

Offset

Value of the offset for each row in `Xnew`. `Offset` can be a vector the same length as `Xnew`, or a scalar that applies to each row. The offset is used as an additional predictor with a coefficient value fixed at 1. In other words, if `b` is the fitted coefficient vector, and `link` is the link function,

$$\text{link}(\text{ypred}) = \text{Offset} + \text{Xnew} * \text{b}.$$

Default: `zeros(size(Xnew,1))`

Simultaneous

Logical value specifying whether the confidence bounds are for all predictor values simultaneously (`true`), or hold for each individual predictor value (`false`). Simultaneous bounds are wider than separate bounds, because it is more stringent to require that the entire curve be within the bounds than to require that the curve at a single predictor value be within the bounds.

For details, see `polyconf`.

Default: `false`

Output Arguments

ypred

Vector of predicted mean values at `Xnew`.

yci

Confidence intervals, a two-column matrix with each row providing one interval. The meaning of the confidence interval depends on the settings of the name-value pairs.

Examples

Generalized Linear Model Predictions

Create a generalized linear model, and predict its response to new data.

Generate artificial data for the model using Poisson random numbers with two underlying predictors `X(1)` and `X(2)`.

```
rng('default') % for reproducibility
rndvars = randn(100,2);
X = [2+rndvars(:,1),rndvars(:,2)];
mu = exp(1 + X*[1;2]);
y = poissrnd(mu);
```

Create a generalized linear regression model of Poisson data.

```
mdl = GeneralizedLinearModel.fit(X,y,...
    'y ~ x1 + x2','distr','poisson');
```

Create points for prediction.

GeneralizedLinearModel.predict

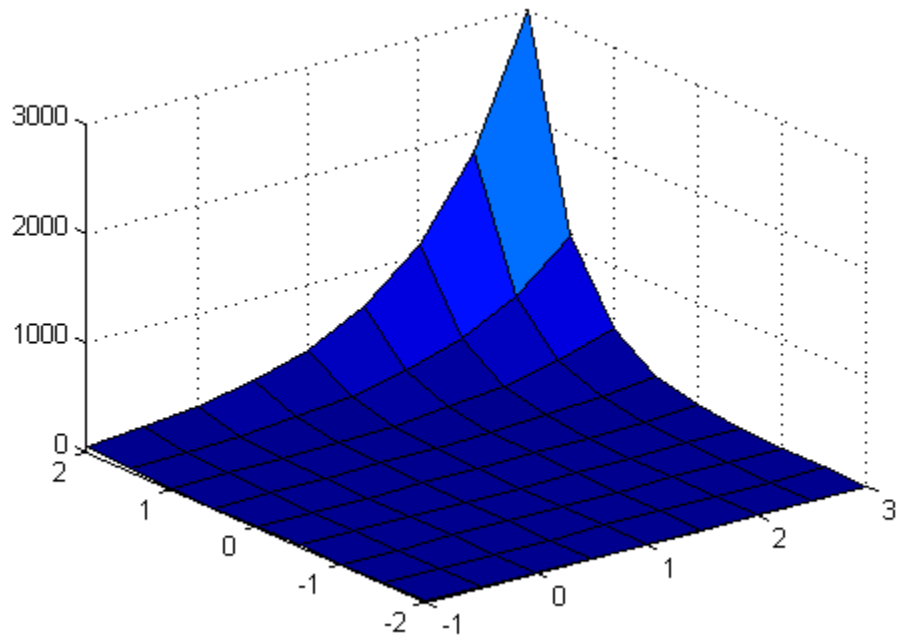
```
[Xtest1 Xtest2] = meshgrid(-1:.5:3, -2:.5:2);  
Xnew = [Xtest1(:), Xtest2(:)];
```

Predict responses at the new points.

```
ypred = predict mdl, Xnew);
```

Plot the predictions.

```
surf(Xtest1, Xtest2, reshape(ypred, 9, 9))
```



Create confidence intervals on the predictions.

```
[ypred yci] = predict(mdl, Xnew);
```

Alternatives

`feval` gives the same predictions, but uses separate input arrays for each predictor, instead of one input array containing all predictors.

`random` predicts with added noise.

See Also

`GeneralizedLinearModel` | `random` |

Related Examples

- “predict” on page 9-166
- “Generalized Linear Model Workflow” on page 9-171

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.predict

Purpose Predict response of linear regression model

Syntax

```
ypred = predict mdl,Xnew  
[ypred,yci] = predict mdl,Xnew  
[ypred,yci] = predict mdl,Xnew,Name,Value)
```

Description `ypred = predict mdl,Xnew` returns the predicted response of the `mdl` linear regression model to the points in `Xnew`.

`[ypred,yci] = predict mdl,Xnew` returns confidence intervals for the true mean responses.

`[ypred,yci] = predict mdl,Xnew,Name,Value)` predicts responses with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For predictions with added noise, use `random`.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

Xnew

Points at which `mdl` predicts responses.

- If `Xnew` is a dataset array, it must contain the predictor names in `mdl`.
- If `Xnew` is a numeric matrix, it must have the same number of variables (columns) as was used to create `mdl`. Furthermore, all variables used in creating `mdl` must be numeric.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can

specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

alpha

Positive scalar from 0 to 1. Confidence level of y_{ci} is $100(1 - \text{alpha})\%$.

Default: 0.05, meaning a 95% confidence interval.

Prediction

String specifying the type of prediction:

- 'curve' — `predict` predicts confidence bounds for the fitted mean values.
- 'observation' — `predict` predicts confidence bounds for the new observations. This results in wider bounds because the error in a new observation is equal to the error in the estimated mean value, plus the variability in the observation from the true mean.

For details, see `polyconf`.

Default: 'curve'

Simultaneous

Logical value specifying whether the confidence bounds are for all predictor values simultaneously (`true`), or hold for each individual predictor value (`false`). Simultaneous bounds are wider than separate bounds, because it is more stringent to require that the entire curve be within the bounds than to require that the curve at a single predictor value be within the bounds.

For details, see `polyconf`.

Default: `false`

LinearModel.predict

Output Arguments

ypred

Vector of predicted mean values at Xnew.

yci

Confidence intervals, a two-column matrix with each row providing one interval. The meaning of the confidence interval depends on the settings of the name-value pairs.

Examples

Predict Response to Data

Create a model of car mileage as a function of weight, and predict the response.

Create a quadratic model of car mileage as a function of weight from the carsmall data.

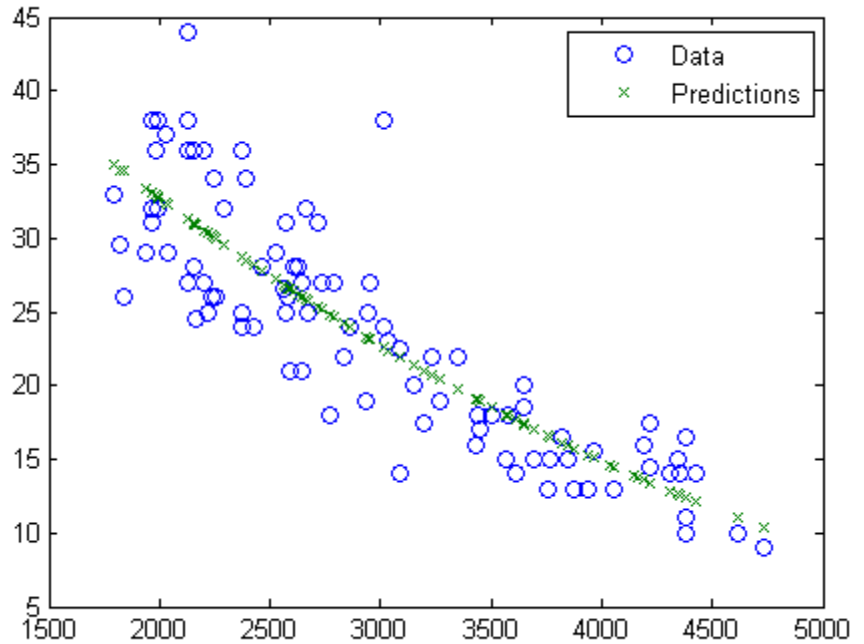
```
load carsmall
X = Weight;
y = MPG;
mdl = LinearModel.fit(X,y,'quadratic');
```

Create predicted responses to the data.

```
Xnew = X;
ypred = predict(mdl,Xnew);
```

Plot the original responses and the predicted responses to see how they differ.

```
plot(X,y,'o',Xnew,ypred,'x')
legend('Data','Predictions')
```



Alternatives

`feval` gives the same predictions, but uses multiple input arrays with one component in each input argument. `feval` can be simpler to use with a model created from a dataset array `ds`. `feval` does not give confidence intervals on its predictions.

`random` predicts with added noise.

See Also

`feval` | `LinearModel` | `LinearModel.fit` | `random` | `LinearModel.stepwise`

Tutorials

- “predict” on page 9-36
- “Linear Regression Workflow” on page 9-40

LinearModel.predict

How To

- “Linear Regression” on page 9-7

Purpose Predict class label for test data

Syntax
`cpre = predict(nb,test)`
`cpre = predict(...,'HandleMissing',val)`

Description `cpre = predict(nb,test)` classifies each row of data in `test` into one of the classes according to the `NaiveBayes` classifier `nb`, and returns the predicted class level `cpre`. `test` is an `N-by-nb.ndims` matrix, where `N` is the number of observations in the test data. Rows of `test` correspond to points, columns of `test` correspond to features. `cpre` is an `N-by-1` vector of the same type as `nb.CLevels`, and it indicates the class to which each row of `test` has been assigned.

`cpre = predict(...,'HandleMissing',val)` specifies how `predict` treats NaN (missing values). `val` can be one of the following:

- | | |
|--------------------|---|
| 'off'
(default) | Observations with NaN in any of the columns are not classified into any class. The corresponding rows in <code>post</code> and <code>logp</code> are NaN. The corresponding rows in <code>cpre</code> are NaN (if <code>obj.clevels</code> is numeric or logical), empty strings (if <code>obj.clevels</code> is char or cell array of strings) or <code><undefined></code> (if <code>obj.clevels</code> is categorical). |
| 'on' | For observations having NaN in some (but not all) columns, <code>post</code> and <code>predict</code> computes <code>cpre</code> using the columns with non-NaN values. Corresponding <code>logp</code> values are NaN. |

See Also `NaiveBayes` | `fit` | `posterior`

NonLinearModel.predict

Purpose Predict response of nonlinear regression model

Syntax

```
y_pred = predict mdl, X_new
[y_pred, y_ci] = predict mdl, X_new
[y_pred, y_ci] = predict mdl, X_new, Name, Value
```

Description `y_pred = predict mdl, X_new` returns the predicted response of the `mdl` nonlinear regression model to the points in `X_new`.

`[y_pred, y_ci] = predict mdl, X_new` returns confidence intervals for the true mean responses.

`[y_pred, y_ci] = predict mdl, X_new, Name, Value` predicts responses with additional options specified by one or more `Name, Value` pair arguments.

- Tips**
- For predictions with added noise, use `random`.
 - For a syntax that can be easier to use with models created from dataset arrays, try `feval`.

Input Arguments

mdl

Nonlinear regression model, constructed by `NonLinearModel.fit`.

Xnew

Points at which `mdl` predicts responses.

- If `Xnew` is a dataset array, it must contain the predictor names in `mdl`.
- If `Xnew` is a numeric matrix, it must have the same number of variables (columns) as was used to create `mdl`. Furthermore, all variables used in creating `mdl` must be numeric.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can

specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

alpha

Positive scalar from 0 to 1. Confidence level of `yci` is $100(1 - \text{alpha})\%$.

Default: 0.05, meaning a 95% confidence interval.

Prediction

String specifying the type of prediction:

- 'curve' — `predict` predicts confidence bounds for the fitted mean values.
- 'observation' — `predict` predicts confidence bounds for the new observations. This results in wider bounds because the error in a new observation is equal to the error in the estimated mean value, plus the variability in the observation from the true mean.

For details, see `polyconf`.

Default: 'curve'

Simultaneous

Logical value specifying whether the confidence bounds are for all predictor values simultaneously (`true`), or hold for each individual predictor value (`false`). Simultaneous bounds are wider than separate bounds, because it is more stringent to require that the entire curve be within the bounds than to require that the curve at a single predictor value be within the bounds.

For details, see `polyconf`.

Default: `false`

NonLinearModel.predict

Weights

Vector of real, positive value weights or a function handle.

- If you specify a vector, then it must have the same number of elements as the number of observations (or rows) in `Xnew`.
- If you specify a function handle, then the function must accept a vector of predicted response values as input, and return a vector of real positive weights as output.

Given weights, `W`, `predict` estimates the error variance at observation `i` by $MSE * (1/W(i))$, where `MSE` is the mean squared error.

Default: No weights

Output Arguments

`ypred`

Vector of predicted mean values at `Xnew`.

`yci`

Confidence intervals, a two-column matrix with each row providing one interval. The meaning of the confidence interval depends on the settings of the name-value pairs.

Examples

Predict Responses

Create a nonlinear model of car mileage as a function of weight, and predict the response.

Create an exponential model of car mileage as a function of weight from the `carsmall` data. Scale the weight by a factor of 1000 so all the variables are roughly equal in size.

```
load carsmall
X = Weight;
y = MPG;
modelfun = 'y ~ b1 + b2*exp(-b3*x/1000)';
```



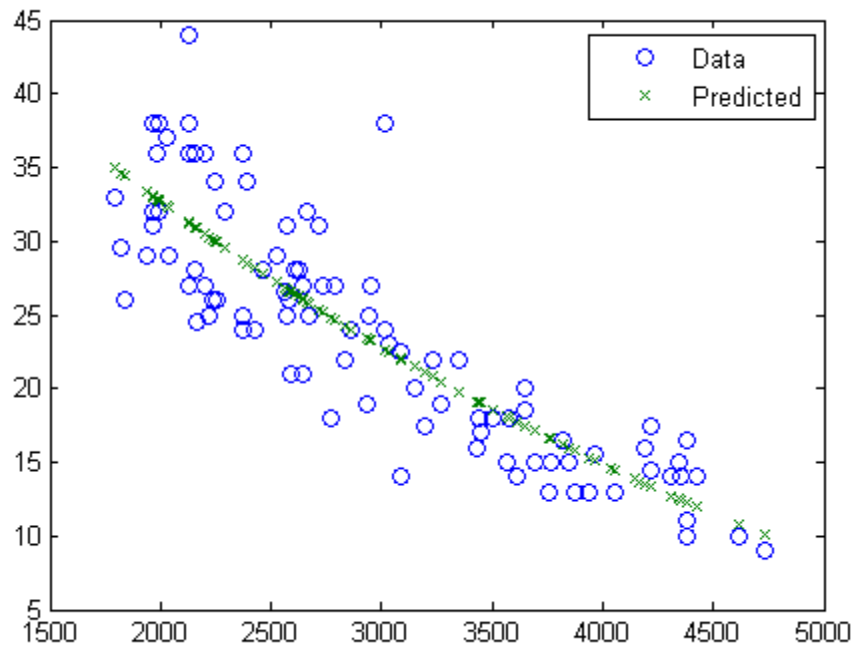
```
beta0 = [1 1 1];  
mdl = NonLinearModel.fit(X,y,modelfun,beta0);
```

Create predicted responses to the data.

```
Xnew = X;  
ypred = predict(mdl,Xnew);
```

Plot the original responses and the predicted responses to see how they differ.

```
plot(X,y,'o',X,ypred,'x')  
legend('Data','Predicted')
```



NonLinearModel.predict

Confidence Intervals for Predictions

Create a nonlinear model of car mileage as a function of weight, and examine confidence intervals of some responses.

Create an exponential model of car mileage as a function of weight from the `carsmall` data. Scale the weight by a factor of 1000 so all the variables are roughly equal in size.

```
load carsmall
X = Weight;
y = MPG;
modelfun = 'y ~ b1 + b2*exp(-b3*x/1000)';
beta0 = [1 1 1];
mdl = NonLinearModel.fit(X,y,modelfun,beta0);
```

Create predicted responses to the smallest, mean, and largest data points.

```
Xnew = [min(X);mean(X);max(X)];
[ypred,yci] = predict(mdl,Xnew)
```

```
ypred =
    34.9469
    22.6868
    10.0617
```

```
yci =
    32.5212    37.3726
    21.4061    23.9674
     7.0148    13.1086
```

Simultaneous Confidence Intervals for Robust Fit Curve

Generate sample data from the nonlinear regression model

$$y = b_1 + b_2 \exp\{-b_3 x\} + \varepsilon,$$

where b_1 , b_2 , and b_3 are coefficients, and the error term is normally distributed with mean 0 and standard deviation 0.5.

```
modelfun = @(b,x)(b(1)+b(2)*exp(-b(3)*x));
```

```
rng('default') % for reproducibility  
b = [1;3;2];  
x = exprnd(2,100,1);  
y = modelfun(b,x) + normrnd(0,0.5,100,1);
```

Fit the nonlinear model using robust fitting options.

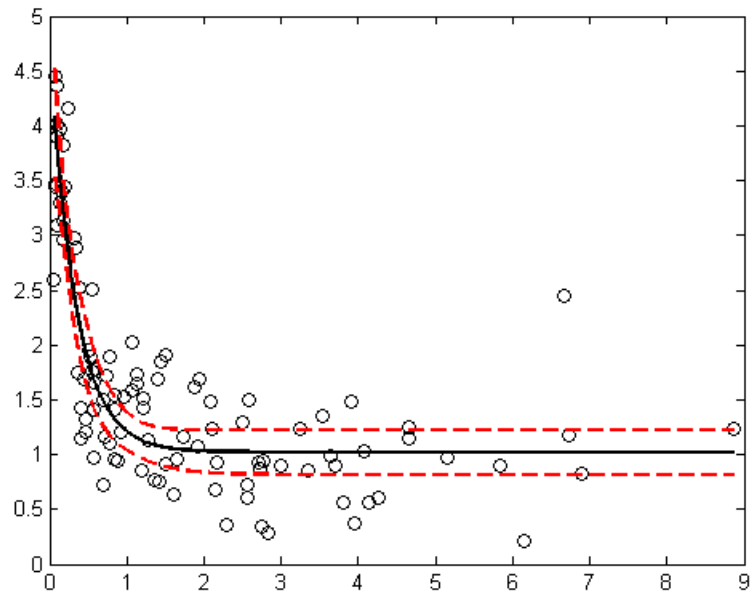
```
opts = statset('nlinfit');  
opts.RobustWgtFun = 'bisquare';  
b0 = [2;2;2];  
mdl = NonLinearModel.fit(x,y,modelfun,b0,'Options',opts);
```

Plot the fitted regression model and simultaneous 95% confidence bounds.

```
xrange = [min(x):.01:max(x)]';  
[ypred,yci] = predict(mdl,xrange,'Simultaneous',true);
```

```
figure()  
plot(x,y,'ko') % observed data  
hold on  
plot(xrange,ypred,'k','LineWidth',2)  
plot(xrange,yci,'r--','LineWidth',1.5)
```

NonLinearModel.predict



Confidence Interval Using Observation Weights

Load sample data.

```
S = load('reaction');  
X = S.reactants;  
y = S.rate;  
beta0 = S.beta;
```

Specify a function handle for observation weights, then fit the Hougen-Watson model to the rate data using the specified observation weights function.

```
a = 1; b = 1;  
weights = @(yhat) 1./((a + b*abs(yhat)).^2);  
mdl = NonLinearModel.fit(X,y,@hougen,beta0,'Weights',weights);
```

Compute the 95% prediction interval for a new observation with reactant levels [100,100,100] using the observation weight function.

```
[ypred,yci] = predict mdl, [100,100,100], 'Prediction', 'observation', ...  
                    'Weights', weights)
```

```
ypred =
```

```
    1.8149
```

```
yci =
```

```
    1.5264    2.1033
```

References

[1] Lane, T. P. and W. H. DuMouchel. “Simultaneous Confidence Intervals in Multiple Regression.” *The American Statistician*. Vol. 48, No. 4, 1994, pp. 315–321.

[2] Seber, G. A. F., and C. J. Wild. *Nonlinear Regression*. Hoboken, NJ: Wiley-Interscience, 2003.

See Also

NonLinearModel | random |

Related Examples

- “Predict or Simulate Responses to New Data” on page 9-206
- “Nonlinear Regression Workflow” on page 9-210

Concepts

- “Nonlinear Regression” on page 9-196

TreeBagger.predict

Purpose Predict response

Syntax

```
Y = predict(B,X)
[Y,stdevs] = predict(B,X)
[Y,scores] = predict(B,X)
[Y,scores,stdevs] = predict(B,X)
Y = predict(B,X,'param1',val1,'param2',val2,...)
```

Description `Y = predict(B,X)` computes predicted response of the trained ensemble `B` for data `X`. The output has one prediction for each row of `X`. The returned `Y` is a cell array of strings for classification and a numeric array for regression.

For regression, `[Y,stdevs] = predict(B,X)` also returns standard deviations of the computed responses over the ensemble of the grown trees.

For classification, `[Y,scores] = predict(B,X)` returns scores for all classes. `scores` is a matrix with one row per observation and one column per class. For each observation and each class, the score generated by each tree is the probability of this observation originating from this class computed as the fraction of observations of this class in a tree leaf. `predict` averages these scores over all trees in the ensemble.

`[Y,scores,stdevs] = predict(B,X)` also returns standard deviations of the computed scores for classification. `stdevs` is a matrix with one row per observation and one column per class, with standard deviations taken over the ensemble of the grown trees.

`Y = predict(B,X,'param1',val1,'param2',val2,...)` specifies optional parameter name/value pairs:

'trees'	Array of tree indices to use for computation of responses. Default is 'all'.
'treeweights'	Array of NTrees weights for weighting votes from the specified trees.
'useifort'	Logical matrix of size Nobs-by-NTrees indicating which trees to use to make predictions for each observation. By default all trees are used for all observations.

See Also

`CompactTreeBagger.predict`

CompactClassificationEnsemble.predictorImportance

Purpose Estimates of predictor importance

Syntax
`imp = predictorImportance(ens)`
`[imp,ma] = predictorImportance(ens)`

Description `imp = predictorImportance(ens)` computes estimates of predictor importance for `ens` by summing these estimates over all weak learners in the ensemble. `imp` has one element for each input predictor in the data used to train this ensemble. A high value indicates that this predictor is important for `ens`.

`[imp,ma] = predictorImportance(ens)` returns a P-by-P matrix with predictive measures of association for P predictors, when the learners in `ens` contain surrogate splits. See “Definitions” on page 20-1879.

Input Arguments

ens
A classification ensemble created by `fitensemble`, or by the `compact` method.

Output Arguments

imp
A row vector with the same number of elements as the number of predictors (columns) in `ens.X`. The entries are the estimates of predictor importance, with 0 representing the smallest possible importance.

ma
A P-by-P matrix of predictive measures of association for P predictors. Element `ma(I,J)` is the predictive measure of association averaged over surrogate splits on predictor J for which predictor I is the optimal split predictor. `predictorImportance` averages this predictive measure of association over all trees in the ensemble.

Definitions

Predictor Importance

`predictorImportance` computes estimates of predictor importance for `ens` by summing changes in the *risk* due to splits on every predictor and dividing the sum by the number of tree nodes. If `ens` is grown without surrogate splits, this sum is taken over best splits found at each branch node. If `ens` is grown with surrogate splits, this sum is taken over all splits at each branch node including surrogate splits. `imp` has one element for each input predictor in the data used to train `ens`. Predictor importance associated with this split is computed as the difference between the risk for the parent node and the total risk for the two children.

Impurity and Node Error

`ClassificationTree` splits nodes based on either *impurity* or *node error*. Impurity means one of several things, depending on your choice of the `SplitCriterion` name-value pair:

- Gini's Diversity Index (`gdi`) — The Gini index of a node is

$$1 - \sum_i p^2(i),$$

where the sum is over the classes i at the node, and $p(i)$ is the observed fraction of classes with class i that reach the node. A node with just one class (a *pure* node) has Gini index 0; otherwise the Gini index is positive. So the Gini index is a measure of node impurity.

- Deviance ('`deviance`') — With $p(i)$ defined as for the Gini index, the deviance of a node is

$$-\sum_i p(i) \log p(i).$$

A pure node has deviance 0; otherwise, the deviance is positive.

- Twoing rule ('`twoing`') — Twoing is not a purity measure of a node, but is a different measure for deciding how to split a node. Let $L(i)$ denote the fraction of members of class i in the left child node after a

CompactClassificationEnsemble.predictorImportance

split, and $R(i)$ denote the fraction of members of class i in the right child node after a split. Choose the split criterion to maximize

$$P(L)P(R)\left(\sum_i |L(i) - R(i)|\right)^2,$$

where $P(L)$ and $P(R)$ are the fractions of observations that split to the left and right respectively. If the expression is large, the split made each child node purer. Similarly, if the expression is small, the split made each child node similar to each other, and hence similar to the parent node, and so the split did not increase node purity.

- Node error — The node error is the fraction of misclassified classes at a node. If j is the class with largest number of training samples at a node, the node error is

$$1 - p(j).$$

Predictive Measure of Association

The predictive measure of association between the optimal split on variable i and a surrogate split on variable j is:

$$\lambda_{i,j} = \frac{\min(P_L, P_R) - (1 - P_{L_i L_j} - P_{R_i R_j})}{\min(P_L, P_R)}.$$

Here

- P_L and P_R are the node probabilities for the optimal split of node i into Left and Right nodes respectively.
- $P_{L_i L_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Left.
- $P_{R_i R_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Right.

CompactClassificationEnsemble.predictorImportance

Clearly, λ_{ij} lies from $-\infty$ to 1. Variable j is a worthwhile surrogate split for variable i if $\lambda_{ij} > 0$.

Element $ma(i, j)$ is the predictive measure of association averaged over surrogate splits on predictor j for which predictor i is the optimal split predictor. This average is computed by summing positive values of the predictive measure of association over optimal splits on predictor i and surrogate splits on predictor j and dividing by the total number of optimal splits on predictor i , including splits for which the predictive measure of association between predictors i and j is negative.

Examples

Estimate the predictor importance for all variables in the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
imp = predictorImportance(ens)

imp =
    0.0001    0.0005    0.0384    0.0146
```

The first two predictors are not very important in ens.

Estimate the predictor importance for all variables in the Fisher iris data for an ensemble where the trees contain surrogate splits:

```
load fisheriris
surrtree = ClassificationTree.template('Surrogate','on');
ens2 = fitensemble(meas,species,'AdaBoostM2',100,surrtree);
[imp2,ma] = predictorImportance(ens2)

imp2 =
    0.0224    0.0142    0.0525    0.0508

ma =
    1.0000         0    0.0001    0.0001
    0.0115    1.0000    0.0023    0.0054
```

CompactClassificationEnsemble.predictorImportance

0.2810	0.1747	1.0000	0.5372
0.0789	0.0463	0.2339	1.0000

The first two predictors show much more importance than in the previous example.

See Also

`predictorImportance`

CompactClassificationTree.predictorImportance

Purpose	Estimates of predictor importance
Syntax	<code>imp = predictorImportance(tree)</code>
Description	<code>imp = predictorImportance(tree)</code> computes estimates of predictor importance for <code>tree</code> by summing changes in the risk due to splits on every predictor and dividing the sum by the number of tree nodes.
Input Arguments	tree A classification tree created by <code>ClassificationTree.fit</code> , or by the <code>compact</code> method.
Output Arguments	imp A row vector with the same number of elements as the number of predictors (columns) in <code>tree.X</code> . The entries are the estimates of predictor importance, with 0 representing the smallest possible importance.
Definitions	Predictor Importance <p><code>predictorImportance</code> computes estimates of predictor importance for <code>tree</code> by summing changes in the <i>risk</i> due to splits on every predictor and dividing the sum by the number of tree nodes. If <code>tree</code> is grown without surrogate splits, this sum is taken over best splits found at each branch node. If <code>tree</code> is grown with surrogate splits, this sum is taken over all splits at each branch node including surrogate splits. <code>imp</code> has one element for each input predictor in the data used to train <code>tree</code>. Predictor importance associated with this split is computed as the difference between the risk for the parent node and the total risk for the two children.</p> <p>Estimates of predictor importance do not depend on the order of predictors if you use surrogate splits, but do depend on the order if you do not use surrogate splits.</p> <p>If you use surrogate splits, <code>predictorImportance</code> computes estimates before the tree is reduced by pruning or merging leaves. If you do not</p>

CompactClassificationTree.predictorImportance

use surrogate splits, `predictorImportance` computes estimates after the tree is reduced by pruning or merging leaves. Therefore, reducing the tree by pruning affects the predictor importance for a tree grown without surrogate splits, and does not affect the predictor importance for a tree grown with surrogate splits.

Impurity and Node Error

`ClassificationTree` splits nodes based on either *impurity* or *node error*. Impurity means one of several things, depending on your choice of the `SplitCriterion` name-value pair:

- Gini's Diversity Index (`gdi`) — The Gini index of a node is

$$1 - \sum_i p^2(i),$$

where the sum is over the classes i at the node, and $p(i)$ is the observed fraction of classes with class i that reach the node. A node with just one class (a *pure* node) has Gini index 0; otherwise the Gini index is positive. So the Gini index is a measure of node impurity.

- Deviance ('`deviance`') — With $p(i)$ defined as for the Gini index, the deviance of a node is

$$-\sum_i p(i) \log p(i).$$

A pure node has deviance 0; otherwise, the deviance is positive.

- Twoing rule ('`twoing`') — Twoing is not a purity measure of a node, but is a different measure for deciding how to split a node. Let $L(i)$ denote the fraction of members of class i in the left child node after a split, and $R(i)$ denote the fraction of members of class i in the right child node after a split. Choose the split criterion to maximize

$$P(L)P(R) \left(\sum_i |L(i) - R(i)| \right)^2,$$

CompactClassificationTree.predictorImportance

where $P(L)$ and $P(R)$ are the fractions of observations that split to the left and right respectively. If the expression is large, the split made each child node purer. Similarly, if the expression is small, the split made each child node similar to each other, and hence similar to the parent node, and so the split did not increase node purity.

- Node error — The node error is the fraction of misclassified classes at a node. If j is the class with largest number of training samples at a node, the node error is

$$1 - p(j).$$

Examples

Estimate the predictor importance for all variables in the Fisher iris data:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
imp = predictorImportance(tree)
```

```
imp =
      0      0    0.0403    0.0303
```

The first two elements of `imp` are zero. Therefore, the first two predictors do not enter into tree calculations for classifying irises.

Estimate the predictor importance for all variables in the Fisher iris data for a tree grown with surrogate splits:

```
tree2 = ClassificationTree.fit(meas,species,...
    'Surrogate','on');
imp2 = predictorImportance(tree2)
```

```
imp2 =
    0.0287    0.0136    0.0560    0.0556
```

In this case, all predictors have some importance. As you expect by comparing to the first example, the first two predictors are less important than the final two.

CompactClassificationTree.predictorImportance

Estimates of predictor importance do not depend on the order of predictors if you use surrogate splits, but do depend on the order if you do not use surrogate splits. For example, permute the order of the data columns in the previous example:

```
load fisheriris
meas3 = meas(:, [4 1 3 2]);
tree3 = ClassificationTree.fit(meas3, species);
imp3 = predictorImportance(tree2)
```

```
imp3 =
    0.0674         0    0.0033         0
```

The estimates of predictor importance are not a permutation of `imp` from the first example.

Estimate the predictor importance using surrogate splits.

```
tree4 = ClassificationTree.fit(meas3, species, ...
    'Surrogate', 'on');
imp4 = predictorImportance(tree4)
```

```
imp4 =
    0.0556    0.0287    0.0560    0.0136
```

`imp4` is a permutation of `imp2`, demonstrating that estimates of predictor importance do not depend on the order of predictors with surrogate splits.

See Also

`predictorImportance`

CompactRegressionEnsemble.predictorImportance

Purpose	Estimates of predictor importance
Syntax	<code>imp = predictorImportance(ens)</code> <code>[imp,ma] = predictorImportance(ens)</code>
Description	<p><code>imp = predictorImportance(ens)</code> computes estimates of predictor importance for <code>ens</code> by summing these estimates over all weak learners in the ensemble. <code>imp</code> has one element for each input predictor in the data used to train this ensemble. A high value indicates that this predictor is important for <code>ens</code>.</p> <p><code>[imp,ma] = predictorImportance(ens)</code> returns a P-by-P matrix with predictive measures of association for P predictors.</p>
Input Arguments	<p>ens</p> <p>A regression ensemble created by <code>fitensemble</code>, or by the <code>compact</code> method.</p>
Output Arguments	<p>imp</p> <p>A row vector with the same number of elements as the number of predictors (columns) in <code>ens.X</code>. The entries are the estimates of predictor importance, with 0 representing the smallest possible importance.</p> <p>ma</p> <p>A P-by-P matrix of predictive measures of association for P predictors. Element <code>ma(I,J)</code> is the predictive measure of association averaged over surrogate splits on predictor J for which predictor I is the optimal split predictor. <code>predictorImportance</code> averages this predictive measure of association over all trees in the ensemble.</p>
Definitions	<p>Predictor Importance</p> <p><code>predictorImportance</code> computes estimates of predictor importance for tree by summing changes in the mean squared error (MSE) due to</p>

CompactRegressionEnsemble.predictorImportance

splits on every predictor and dividing the sum by the number of tree nodes. If the tree is grown without surrogate splits, this sum is taken over best splits found at each branch node. If the tree is grown with surrogate splits, this sum is taken over all splits at each branch node including surrogate splits. `imp` has one element for each input predictor in the data used to train this tree. At each node, MSE is estimated as node error weighted by the node probability. Variable importance associated with this split is computed as the difference between MSE for the parent node and the total MSE for the two children.

Predictive Measure of Association

The predictive measure of association between the optimal split on variable i and a surrogate split on variable j is:

$$\lambda_{i,j} = \frac{\min(P_L, P_R) - (1 - P_{L_i L_j} - P_{R_i R_j})}{\min(P_L, P_R)}.$$

Here

- P_L and P_R are the node probabilities for the optimal split of node i into Left and Right nodes respectively.
- $P_{L_i L_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Left.
- $P_{R_i R_j}$ is the probability that both (optimal) node i and (surrogate) node j send an observation to the Right.

Clearly, $\lambda_{i,j}$ lies from $-\infty$ to 1. Variable j is a worthwhile surrogate split for variable i if $\lambda_{i,j} > 0$.

Element `ma(i, j)` is the predictive measure of association averaged over surrogate splits on predictor j for which predictor i is the optimal split predictor. This average is computed by summing positive values of the predictive measure of association over optimal splits on predictor i and surrogate splits on predictor j and dividing by the total number of

CompactRegressionEnsemble.predictorImportance

optimal splits on predictor i , including splits for which the predictive measure of association between predictors i and j is negative.

Examples

Estimate the predictor importance for all numeric variables in the `carsmall` data:

```
load carsmall
X = [Acceleration Cylinders Displacement ...
     Horsepower Model_Year Weight];
ens = fitensemble(X,MPG,'LSBoost',100,'Tree');
imp = predictorImportance(ens)

imp =
    0.0082         0    0.0049    0.0133    0.0142    0.1737
```

The weight (last predictor) has the most impact on mileage (MPG). The second predictor has importance 0; this means the number of cylinders has no impact on predictions made with `ens`.

Estimate the predictor importance for all variables in the `carsmall` data for an ensemble where the trees contain surrogate splits:

```
load carsmall
surrtree = RegressionTree.template('Surrogate','on');
X = [Acceleration Cylinders Displacement ...
     Horsepower Model_Year Weight];
ens2 = fitensemble(X,MPG,'LSBoost',100,surrtree);
[imp2,ma] = predictorImportance(ens2)

imp2 =
    0.0725    0.1342    0.1425    0.1397    0.1380    0.1855

ma =
    1.0000    0.0414    0.0607    0.0782    0.0102    0.0322
         0    1.0000         0         0         0         0
    0.0441    0.0704    1.0000    0.0883    0.0175    0.0913
    0.0944    0.1166    0.1400    1.0000    0.0390    0.1308
```

CompactRegressionEnsemble.predictorImportance

0.0121	0.0139	0.0127	0.0127	1.0000	0.0113
0.0818	0.1317	0.2072	0.1878	0.0340	1.0000

While weight (last predictor) still has the most impact on mileage (MPG), this estimate has the second predictor (number of cylinders) is essentially tied for third most important predictor.

See Also

`predictorImportance`

CompactRegressionTree.predictorImportance

Purpose	Estimates of predictor importance
Syntax	<code>imp = predictorImportance(tree)</code>
Description	<code>imp = predictorImportance(tree)</code> computes estimates of predictor importance for <code>tree</code> by summing changes in the mean squared error due to splits on every predictor and dividing the sum by the number of tree nodes.
Input Arguments	tree A regression tree created by <code>RegressionTree.fit</code> , or by the <code>compact</code> method.
Output Arguments	imp A row vector with the same number of elements as the number of predictors (columns) in <code>tree.X</code> . The entries are the estimates of predictor importance, with 0 representing the smallest possible importance.

Definitions **Predictor Importance**

`predictorImportance` computes estimates of predictor importance for `tree` by summing changes in the mean squared error (MSE) due to splits on every predictor and dividing the sum by the number of tree nodes. If the tree is grown without surrogate splits, this sum is taken over best splits found at each branch node. If the tree is grown with surrogate splits, this sum is taken over all splits at each branch node including surrogate splits. `imp` has one element for each input predictor in the data used to train this tree. At each node, MSE is estimated as node error weighted by the node probability. Variable importance associated with this split is computed as the difference between MSE for the parent node and the total MSE for the two children.

Estimates of predictor importance do not depend on the order of predictors if you use surrogate splits, but do depend on the order if you do not use surrogate splits.

CompactRegressionTree.predictorImportance

If you use surrogate splits, `predictorImportance` computes estimates before the tree is reduced by pruning or merging leaves. If you do not use surrogate splits, `predictorImportance` computes estimates after the tree is reduced by pruning or merging leaves. Therefore, reducing the tree by pruning affects the predictor importance for a tree grown without surrogate splits, and does not affect the predictor importance for a tree grown with surrogate splits.

Examples

Find predictor importance for the `carsmall` data. Use just the numeric predictors:

```
load carsmall
X = [Acceleration Cylinders Displacement ...
     Horsepower Model_Year Weight];
tree = RegressionTree.fit(X,MPG);
imp = predictorImportance(tree)

imp =
    0.0315         0    0.1082    0.0686    0.1629    1.2924
```

The weight (last predictor) has the most impact on mileage (MPG). The second predictor has importance 0; this means the number of cylinders has no impact on predictions made with `tree`.

Estimate the predictor importance for all variables in the `carsmall` data for a tree grown with surrogate splits:

```
load carsmall
X = [Acceleration Cylinders Displacement ...
     Horsepower Model_Year Weight];
tree2 = RegressionTree.fit(X,MPG,...
    'Surrogate','on');
imp2 = predictorImportance(tree2)

imp2 =
    0.5287    1.1977    1.2400    0.7059    1.0677    1.4106
```

CompactRegressionTree.predictorImportance

While weight (last predictor) still has the most impact on mileage (MPG), this estimate has the second predictor (number of cylinders) as the third most important predictor.

See Also `predictorImportance`

princomp

Purpose Principal component analysis (PCA) on data

Syntax

```
[COEFF,SCORE] = princomp(X)
[COEFF,SCORE,latent] = princomp(X)
[COEFF,SCORE,latent,tsquare] = princomp(X)
[...] = princomp(X,'econ')
```

Description `COEFF = princomp(X)` performs principal components analysis (PCA) on the n -by- p data matrix X , and returns the principal component coefficients, also known as loadings. Rows of X correspond to observations, columns to variables. `COEFF` is a p -by- p matrix, each column containing coefficients for one principal component. The columns are in order of decreasing component variance.

`princomp` centers X by subtracting off column means, but does not rescale the columns of X . To perform principal components analysis with standardized variables, that is, based on correlations, use `princomp(zscore(X))`. To perform principal components analysis directly on a covariance or correlation matrix, use `pcacov`.

`[COEFF,SCORE] = princomp(X)` returns `SCORE`, the principal component scores; that is, the representation of X in the principal component space. Rows of `SCORE` correspond to observations, columns to components.

`[COEFF,SCORE,latent] = princomp(X)` returns `latent`, a vector containing the eigenvalues of the covariance matrix of X .

`[COEFF,SCORE,latent,tsquare] = princomp(X)` returns `tsquare`, which contains Hotelling's T^2 statistic for each data point.

The scores are the data formed by transforming the original data into the space of the principal components. The values of the vector `latent` are the variance of the columns of `SCORE`. Hotelling's T^2 is a measure of the multivariate distance of each observation from the center of the data set.

When $n \leq p$, `SCORE(:,n:p)` and `latent(n:p)` are necessarily zero, and the columns of `COEFF(:,n:p)` define directions that are orthogonal to X .

[...] = princomp(X, 'econ') returns only the elements of latent that are not necessarily zero, and the corresponding columns of COEFF and SCORE, that is, when $n \leq p$, only the first $n-1$. This can be significantly faster when p is much larger than n .

Examples

Compute principal components for the ingredients data in the Hald data set, and the variance accounted for by each component.

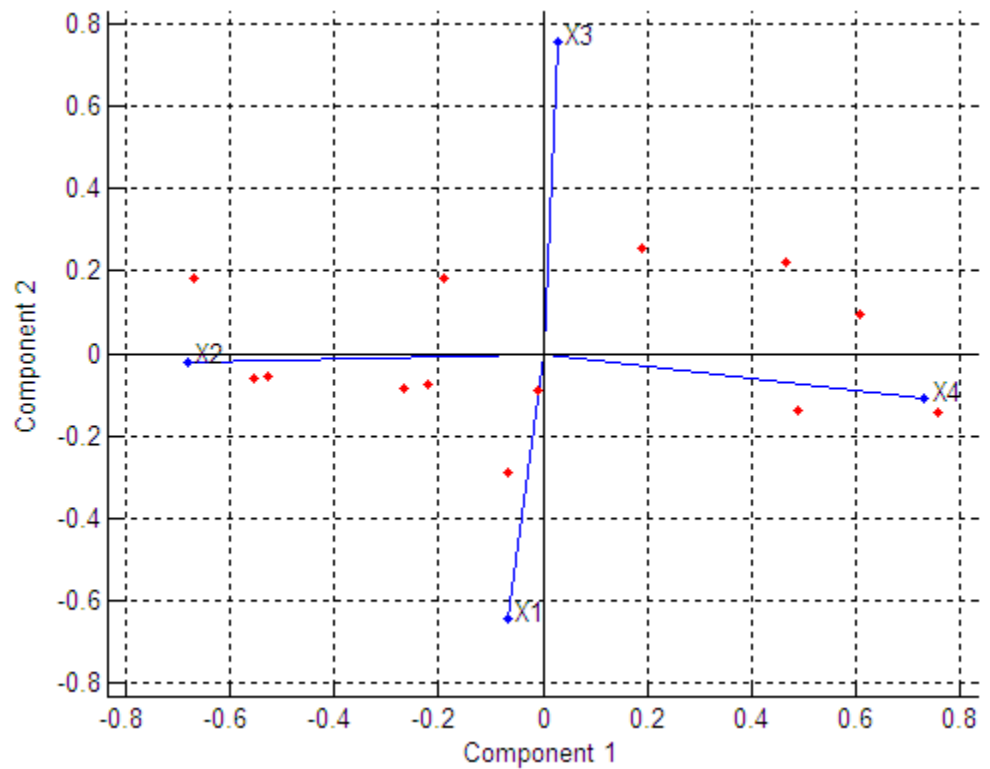
```
load hald;
[pc,score,latent,tsquare] = princomp(ingredients);
pc,latent
```

```
pc =
    0.0678 -0.6460  0.5673 -0.5062
    0.6785 -0.0200 -0.5440 -0.4933
   -0.0290  0.7553  0.4036 -0.5156
   -0.7309 -0.1085 -0.4684 -0.4844
```

```
latent =
    517.7969
     67.4964
     12.4054
      0.2372
```

The following command and plot show that two components account for 98% of the variance:

```
cumsum(latent)./sum(latent)
ans =
    0.86597
    0.97886
    0.9996
     1
biplot(pc(:,1:2), 'Scores', score(:,1:2), 'VarLabels', ...
        {'X1' 'X2' 'X3' 'X4'})
```



For a more detailed example and explanation of this analysis method, see “Principal Component Analysis (PCA)” on page 10-31.

References

- [1] Jackson, J. E., *A User's Guide to Principal Components*, John Wiley and Sons, 1991, p. 592.
- [2] Jolliffe, I. T., *Principal Component Analysis*, 2nd edition, Springer, 2002.
- [3] Krzanowski, W. J. *Principles of Multivariate Analysis: A User's Perspective*. New York: Oxford University Press, 1988.

[4] Seber, G. A. F., *Multivariate Observations*, Wiley, 1984.

See Also

`barttest` | `biplot` | `canoncorr` | `factoran` | `pca` | `pcacov` | `pcares`
| `rotatefactors`

How To

- “Principal Component Analysis (PCA)” on page 10-31

TreeBagger.Prior property

Purpose Prior class probabilities

Description The Prior property is a vector with prior probabilities for classes. This property is empty for ensembles of regression trees.

See Also `classregtree`

Purpose	Object representing probability distribution	
Description	ProbDist is an abstract class representing a probability distribution.	
Construction	ProbDist is an abstract class. You cannot create instances of this class directly. You can construct an object in a subclass, such as ProbDistUnivParam or ProbDistUnivKernel, either by calling the subclass constructors (ProbDistUnivParam.ProbDistUnivParam or ProbDistUnivKernel.ProbDistUnivKernel) or by using the fitdist function.	
Methods	cdf	Return cumulative distribution function (CDF) for ProbDist object
	pdf	Return probability density function (PDF) for ProbDist object
	random	Generate random number drawn from ProbDist object
Properties	DistName	Read-only string containing probability distribution name of ProbDist object
	InputData	Read-only structure containing information about input data to ProbDist object
	Support	Read-only structure containing information about support of ProbDist object
Copy Semantics	Value. To learn how this affects your use of the class, see Copying Objects in the MATLAB Programming Fundamentals documentation.	

ProbDist

See Also

`fitdist` | `ProbDistParametric` | `ProbDistKernel`
| `ProbDistUnivParam` | `ProbDistUnivKernel`
| `ProbDistUnivParam.ProbDistUnivParam` |
`ProbDistUnivKernel.ProbDistUnivKernel`

Superclasses ProbDist

Purpose Object representing nonparametric probability distribution defined by kernel smoothing

Description ProbDistKernel is an abstract class defining the properties and methods of a nonparametric distribution defined by a kernel smoothing function.

Construction ProbDistKernel is an abstract class. You cannot create instances of this class directly. You can construct an object in a subclass, ProbDistUnivKernel, either by calling the subclass constructor, ProbDistUnivKernel.ProbDistUnivKernel, or by using the fitdist function.

Methods	cdf	Return cumulative distribution function (CDF) for ProbDist object
	pdf	Return probability density function (PDF) for ProbDist object
	random	Generate random number drawn from ProbDist object

Note The above methods are inherited from the ProbDist class.

Properties	BandWidth	Read-only value specifying bandwidth of kernel smoothing function for ProbDistKernel object
	DistName	Read-only string containing probability distribution name of ProbDist object

ProbDistKernel

InputData	Read-only structure containing information about input data to ProbDist object
Kernel	Read-only string specifying name of kernel smoothing function for ProbDistKernel object
Support	Read-only structure containing information about support of ProbDist object

Note Some of the above properties are inherited from the ProbDist class.

Copy Semantics

Value. To learn how this affects your use of the class, see Copying Objects in the MATLAB Programming Fundamentals documentation.

See Also

`fitdist` | `ProbDist` | `ProbDistUnivKernel` | `ProbDistUnivKernel.ProbDistUnivKernel`

Superclasses ProbDist

Purpose Object representing parametric probability distribution

Description ProbDistParametric is an abstract class defining the properties and methods of a parametric probability distribution.

Construction ProbDistParametric is an abstract class. You cannot create instances of this class directly. You can construct an object in its subclass, ProbDistUnivParam, either by calling the subclass constructor, ProbDistUnivParam.ProbDistUnivParam, or by using the fitdist function.

Methods	cdf	Return cumulative distribution function (CDF) for ProbDist object
	pdf	Return probability density function (PDF) for ProbDist object
	random	Generate random number drawn from ProbDist object

Note The above methods are inherited from the ProbDist class.

Properties	DistName	Read-only string containing probability distribution name of ProbDist object
	InputData	Read-only structure containing information about input data to ProbDist object

ProbDistParametric

NLogL	Read-only value specifying negative log likelihood for input data to ProbDistParametric object
NumParams	Read-only value specifying number of parameters of ProbDistParametric object
ParamCov	Read-only covariance matrix of parameter estimates of ProbDistParametric object
ParamDescription	Read-only cell array specifying descriptions of parameters of ProbDistParametric object
ParamIsFixed	Read-only logical array specifying fixed parameters of ProbDistParametric object
ParamNames	Read-only cell array specifying names of parameters of ProbDistParametric object
Params	Read-only array specifying values of parameters of ProbDistParametric object
Support	Read-only structure containing information about support of ProbDist object

Note Some of the above properties are inherited from the ProbDist class.

Copy Semantics

Value. To learn how this affects your use of the class, see Copying Objects in the MATLAB Programming Fundamentals documentation.

See Also

`fitdist` | `ProbDist` | `ProbDistUnivParam` |
`ProbDistUnivParam.ProbDistUnivParam`

ProbDistUnivKernel

Superclasses	ProbDistKernel
Purpose	Object representing univariate kernel probability distribution
Description	A ProbDistUnivKernel object represents a univariate nonparametric probability distribution defined by kernel smoothing. You create this object using the <code>fitdist</code> function to fit the distribution to data.
Construction	<code>fitdist</code> Fit probability distribution to data
Methods	<code>cdf</code> Return cumulative distribution function (CDF) for ProbDist object <code>icdf</code> Return inverse cumulative distribution function (ICDF) for ProbDistUnivKernel object <code>iqr</code> Return interquartile range (IQR) for ProbDistUnivKernel object <code>median</code> Return median of ProbDistUnivKernel object <code>pdf</code> Return probability density function (PDF) for ProbDist object <code>random</code> Generate random number drawn from ProbDist object

Note Some of the above methods are inherited from the ProbDistKernel class.

Properties

BandWidth	Read-only value specifying bandwidth of kernel smoothing function for ProbDistKernel object
DistName	Read-only string containing probability distribution name of ProbDist object
InputData	Read-only structure containing information about input data to ProbDist object
Kernel	Read-only string specifying name of kernel smoothing function for ProbDistKernel object
NLogL	Read-only value specifying negative log likelihood for input data to ProbDistUnivKernel object
Support	Read-only structure containing information about support of ProbDist object

Note Some of the above properties are inherited from the ProbDistKernel class.

Copy Semantics

Value. To learn how this affects your use of the class, see Copying Objects in the MATLAB Programming Fundamentals documentation.

References

[1] Bowman, A. W., and A. Azzalini. *Applied Smoothing Techniques for Data Analysis*. New York: Oxford University Press, 1997.

ProbDistUnivKernel

See Also

`fitdist` | `ksdensity` | `ProbDist` | `ProbDistKernel` |
`ProbDistUnivKernel.ProbDistUnivKernel`

Purpose Construct ProbDistUnivKernel object

Syntax $PD = \text{ProbDistUnivKernel}(X)$
 $PD = \text{ProbDistUnivKernel}(X, \text{param1}, \text{val1}, \text{param2}, \text{val2}, \dots)$

Description

Tip Although you can use this constructor function to create a ProbDistUnivKernel object, using the `fitdist` function is an easier way to create the ProbDistUnivKernel object.

$PD = \text{ProbDistUnivKernel}(X)$ creates PD , a ProbDistUnivKernel object, which represents a nonparametric probability distribution, based on a normal kernel smoothing function.

$PD = \text{ProbDistUnivKernel}(X, \text{param1}, \text{val1}, \text{param2}, \text{val2}, \dots)$ specifies optional parameter name/value pairs, as described in the Parameter/Values table. Parameter and value names are case insensitive.

Input Arguments

X A column vector of data.

Note Any NaN values in X are ignored by the fitting calculations.

ProbDistUnivKernel

Parameter	Values
'censoring'	<p>A Boolean vector the same size as X, containing 1s when the corresponding elements in X are right-censored observations and 0s when the corresponding elements are exact observations. Default is a vector of 0s.</p> <hr/> <p>Note Any NaN values in this censoring vector are ignored by the fitting calculations.</p> <hr/>
'frequency'	<p>A vector the same size as X, containing nonnegative integers specifying the frequencies for the corresponding elements in X. Default is a vector of 1s.</p> <hr/> <p>Note Any NaN values in this frequency vector are ignored by the fitting calculations.</p> <hr/>
'kernel'	<p>A string specifying the type of kernel smoother to use. Choices are:</p> <ul style="list-style-type: none">• 'normal' (default)• 'box'• 'triangle'• 'epanechnikov'

Parameter	Values
'support'	Any of the following to specify the support: <ul style="list-style-type: none">• 'unbounded' — Default. If the density can extend over the whole real line.• 'positive' — To restrict it to positive values.• A two-element vector giving finite lower and upper limits for the support of the density.
'width'	A value specifying the bandwidth of the kernel smoothing window. The default is optimal for estimating normal densities, but you may want to choose a smaller value to reveal features such as multiple modes.

Output Arguments

PD

An object in the ProbDistUnivKernel class, which is derived from the ProbDist class. It represents a nonparametric probability distribution.

References

[1] Bowman, A. W., and A. Azzalini. *Applied Smoothing Techniques for Data Analysis*. New York: Oxford University Press, 1997.

See Also

fitdist | ksdensity

ProbDistUnivParam

Superclasses	ProbDistParametric	
Purpose	Object representing univariate parametric probability distribution	
Description	A ProbDistUnivParam object represents a univariate parametric probability distribution. You create this object by using the constructor (ProbDistUnivParam.ProbDistUnivParam) and supplying parameter values, or by using the fitdist function to fit the distribution to data.	
Construction	fitdist	Fit probability distribution to data
	ProbDistUnivParam	Construct ProbDistUnivParam object
Methods	cdf	Return cumulative distribution function (CDF) for ProbDist object
	icdf	Return inverse cumulative distribution function (ICDF) for ProbDistUnivParam object
	iqr	Return interquartile range (IQR) for ProbDistUnivParam object
	mean	Return mean of ProbDistUnivParam object
	median	Return median of ProbDistUnivParam object
	paramci	Return parameter confidence intervals of ProbDistUnivParam object
	pdf	Return probability density function (PDF) for ProbDist object

random	Generate random number drawn from ProbDist object
std	Return standard deviation of ProbDistUnivParam object
var	Return variance of ProbDistUnivParam object

Note Some of the above methods are inherited from the ProbDistParametric class.

Properties

DistName	Read-only string containing probability distribution name of ProbDist object
InputData	Read-only structure containing information about input data to ProbDist object
NLogL	Read-only value specifying negative log likelihood for input data to ProbDistParametric object
NumParams	Read-only value specifying number of parameters of ProbDistParametric object
ParamCov	Read-only covariance matrix of parameter estimates of ProbDistParametric object
ParamDescription	Read-only cell array specifying descriptions of parameters of ProbDistParametric object

ProbDistUnivParam

ParamIsFixed	Read-only logical array specifying fixed parameters of ProbDistParametric object
ParamNames	Read-only cell array specifying names of parameters of ProbDistParametric object
Params	Read-only array specifying values of parameters of ProbDistParametric object
Support	Read-only structure containing information about support of ProbDist object

Note The above properties are inherited from the ProbDistParametric class.

Note Parameter values are also properties. For example, if you create PD, a univariate parametric probability distribution object that represents a normal distribution, then PD.mu and PD.sigma are properties that give the values of the mu and sigma parameters.

Copy Semantics

Value. To learn how this affects your use of the class, see Copying Objects in the MATLAB Programming Fundamentals documentation.

References

[1] Johnson, N. L., S. Kotz, and N. Balakrishnan. *Continuous Univariate Distributions*. Vol. 1, Hoboken, NJ: Wiley-Interscience, 1993.

[2] Johnson, N. L., S. Kotz, and N. Balakrishnan. *Continuous Univariate Distributions*. Vol. 2, Hoboken, NJ: Wiley-Interscience, 1994.

See Also

[fitdist](#) | [ProbDist](#) | [ProbDistParametric](#) | [ProbDistUnivParam.ProbDistUnivParam](#)

How To

- [Appendix B, “Distribution Reference”](#)

ProbDistUnivParam

Purpose Construct ProbDistUnivParam object

Syntax `PD = ProbDistUnivParam(DistName, Params)`

Description `PD = ProbDistUnivParam(DistName, Params)` creates `PD`, a ProbDistUnivParam object, which represents a probability distribution. This distribution is defined by the parametric distribution specified by `DistName`, with parameters specified by the numeric vector `Params`.

Input Arguments

`DistName` A string specifying a distribution. Choices are:

- 'beta'
- 'binomial'
- 'birnbaumsaunders'
- 'exponential'
- 'extreme value' or 'ev'
- 'gamma'
- 'generalized extreme value' or 'gev'
- 'generalized pareto' or 'gp'
- 'inversegaussian'
- 'logistic'
- 'loglogistic'
- 'lognormal'
- 'nakagami'
- 'negative binomial' or 'nbin'
- 'normal'
- 'poisson'

- 'rayleigh'
- 'rician'
- 'tlocationscale'
- 'weibull' or 'wbl'

For more information on these parametric distributions, see Appendix B, “Distribution Reference”.

Params

Numeric vector of distribution parameters. The number and type of parameters depends on the distribution you specify with *DistName*. For information on parameters for each distribution type, see Appendix B, “Distribution Reference”.

Output Arguments

PD

An object in the ProbDistUnivParam class, which is derived from the ProbDist class. It represents a parametric probability distribution.

Examples

- 1 Create an object representing a normal distribution with a mean of 100 and a standard deviation of 10.

```
pd = ProbDistUnivParam('normal',[100 10])
```

```
pd =
```

```
normal distribution
```

```
mu = 100  
sigma = 10
```

ProbDistUnivParam

2 Generate a 4-by-5 matrix of random values from this distribution.

```
random(pd, 4, 5)
```

```
ans =
```

```
105.3767 103.1877 135.7840 107.2540 98.7586  
118.3389 86.9231 127.6944 99.3695 114.8970  
77.4115 95.6641 86.5011 107.1474 114.0903  
108.6217 103.4262 130.3492 97.9503 114.1719
```

References

[1] Johnson, N. L., S. Kotz, and N. Balakrishnan. *Continuous Univariate Distributions*. Vol. 1, Hoboken, NJ: Wiley-Interscience, 1993.

[2] Johnson, N. L., S. Kotz, and N. Balakrishnan. *Continuous Univariate Distributions*. Vol. 2, Hoboken, NJ: Wiley-Interscience, 1994.

See Also

fitdist

How To

- Appendix B, “Distribution Reference”

Purpose Probability plots

Syntax

```

probplot(Y)
probplot(distribution,Y)
probplot(Y,cens,freq)
probplot(ax,Y)
probplot(...,'noref')
probplot(ax,PD)
probplot(ax,fun,params)
h = probplot(...)
```

Description `probplot(Y)` produces a normal probability plot comparing the distribution of the data `Y` to the normal distribution. `Y` can be a single vector, or a matrix with a separate sample in each column. The plot includes a reference line useful for judging whether the data follow a normal distribution.

`probplot` uses midpoint probability plotting positions. The i^{th} sorted value from a sample of size N is plotted against the midpoint in the jump of the empirical CDF on the y axis. With uncensored data, that midpoint is $(i-0.5)/N$. With censored data (see below), the y value is more complicated to compute.

`probplot(distribution,Y)` creates a probability plot for the distribution specified by *distribution*. Acceptable strings for *distribution* are:

- 'exponential' — Exponential probability plot (nonnegative values)
- 'extreme value' — Extreme value probability plot (all values)
- 'lognormal' — Lognormal probability plot (positive values)
- 'normal' — Normal probability plot (all values)
- 'rayleigh' — Rayleigh probability plot (positive values)
- 'weibull' — Weibull probability plot (positive values)

probplot

The y axis scale is based on the selected distribution. The x axis has a log scale for the Weibull and lognormal distributions, and a linear scale for the others.

Not all distributions are appropriate for all data sets, and `probplot` will error when asked to create a plot with a data set that is inappropriate for a specified distribution. Appropriate data ranges for each distribution are given parenthetically in the list above.

`probplot(Y,cens,freq)` or `probplot(distname,Y,cens,freq)` requires a vector Y . `cens` is a vector of the same size as Y and contains 1 for observations that are right-censored and 0 for observations that are observed exactly. `freq` is a vector of the same size as Y , containing integer frequencies for the corresponding elements in Y .

`probplot(ax,Y)` takes a handle `ax` to an existing probability plot, and adds additional lines for the samples in Y . `ax` is a handle for a set of axes.

`probplot(..., 'noref')` omits the reference line.

`probplot(ax,PD)` takes a probability distribution object, `PD`, and adds a fitted line to the axes specified by `ax` to represent the probability distribution specified by `PD`. `PD` is a `ProbDist` object of the `ProbDistUnivParam` class or `ProbDistUnivKernel` class.

`probplot(ax,fun,params)` takes a function `fun` and a set of parameters, `params`, and adds fitted lines to the axes of an existing probability plot specified by `ax`. `fun` is a function handle to a cdf function, specified with `@` (for example, `@wblcdf`). `params` is the set of parameters required to evaluate `fun`, and is specified as a cell array or vector. The function must accept a vector of X values as its first argument, then the optional parameters, and must return a vector of cdf values evaluated at X .

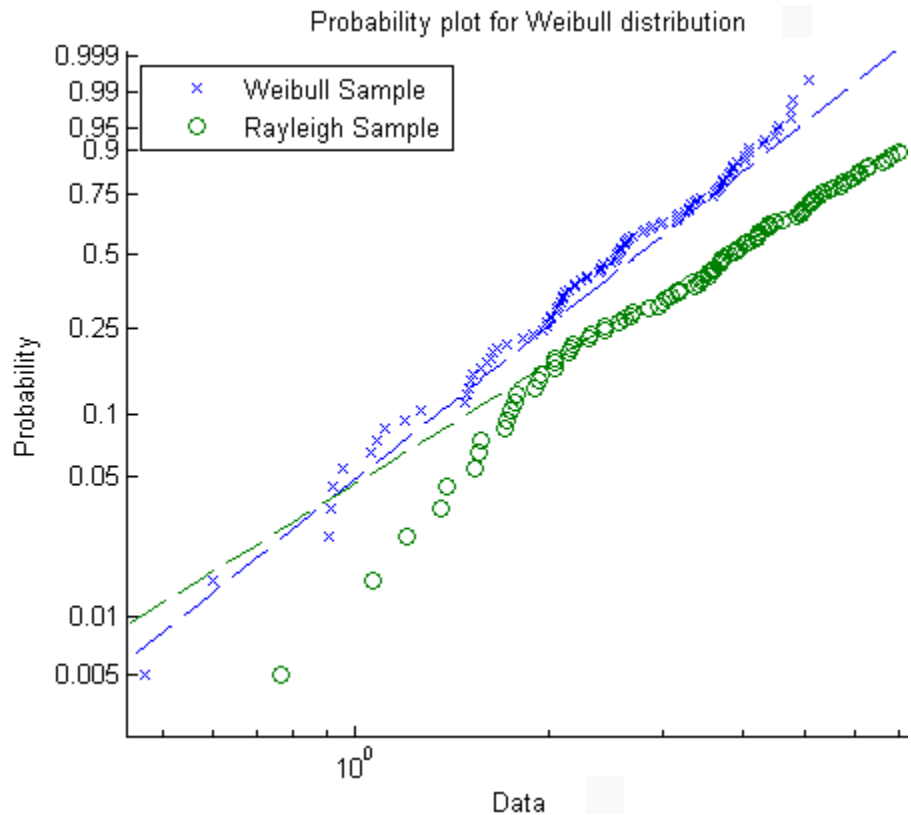
`h = probplot(...)` returns handles to the plotted lines.

Examples

Example 1

The following plot assesses two samples, one from a Weibull distribution and one from a Rayleigh distribution, to see if they may have come from a Weibull population.

```
x1 = wblrnd(3,3,100,1);
x2 = raylrnd(3,100,1);
probplot('weibull',[x1 x2])
legend('Weibull Sample','Rayleigh Sample','Location','NW')
```



Example 2

Consider the following data, with about 20% outliers:

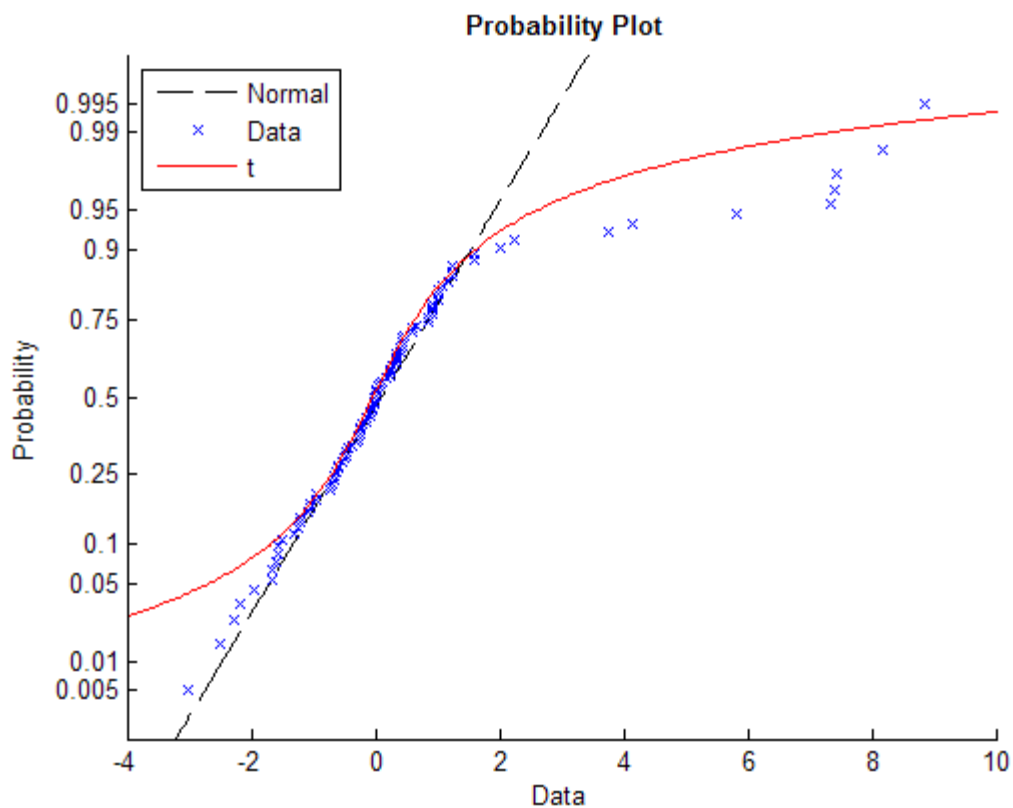
```
left_tail = -exprnd(1,10,1);
right_tail = exprnd(5,10,1);
center = randn(80,1);
```

probplot

```
data = [left_tail;center;right_tail];
```

Neither a normal distribution nor a t distribution fits the tails very well:

```
probplot(data);  
p = mle(data,'dist','tlo');  
t = @(data,mu,sig,df)cdf('tlocation',data,mu,sig,df);  
h = probplot(gca,t,p);  
set(h,'color','r','linestyle','-');  
title('\bf Probability Plot');  
legend('Data','Normal','t','Location','NW');
```



See Also `normplot` | `ecdf` | `wblplot`

Purpose Procrustes analysis

Syntax

```
d = procrustes(X,Y)
[d,Z] = procrustes(X,Y)
[d,Z,transform] = procrustes(X,Y)
[...] = procrustes(...,'scaling',flag)
[...] = procrustes(...,'reflection',flag)
```

Description `d = procrustes(X,Y)` determines a linear transformation (translation, reflection, orthogonal rotation, and scaling) of the points in matrix `Y` to best conform them to the points in matrix `X`. The goodness-of-fit criterion is the sum of squared errors. `procrustes` returns the minimized value of this dissimilarity measure in `d`. `d` is standardized by a measure of the scale of `X`, given by:

```
sum(sum((X-repmat(mean(X,1),size(X,1),1)).^2,1))
```

That is, the sum of squared elements of a centered version of `X`. However, if `X` comprises repetitions of the same point, the sum of squared errors is not standardized.

`X` and `Y` must have the same number of points (rows), and `procrustes` matches `Y(i)` to `X(i)`. Points in `Y` can have smaller dimension (number of columns) than those in `X`. In this case, `procrustes` adds columns of zeros to `Y` as necessary.

`[d,Z] = procrustes(X,Y)` also returns the transformed `Y` values.

`[d,Z,transform] = procrustes(X,Y)` also returns the transformation that maps `Y` to `Z`. `transform` is a structure array with fields:

- `c` — Translation component
- `T` — Orthogonal rotation and reflection component
- `b` — Scale component

That is:

```
c = transform.c;
T = transform.T;
```

```
b = transform.b;
```

```
Z = b*Y*T + c;
```

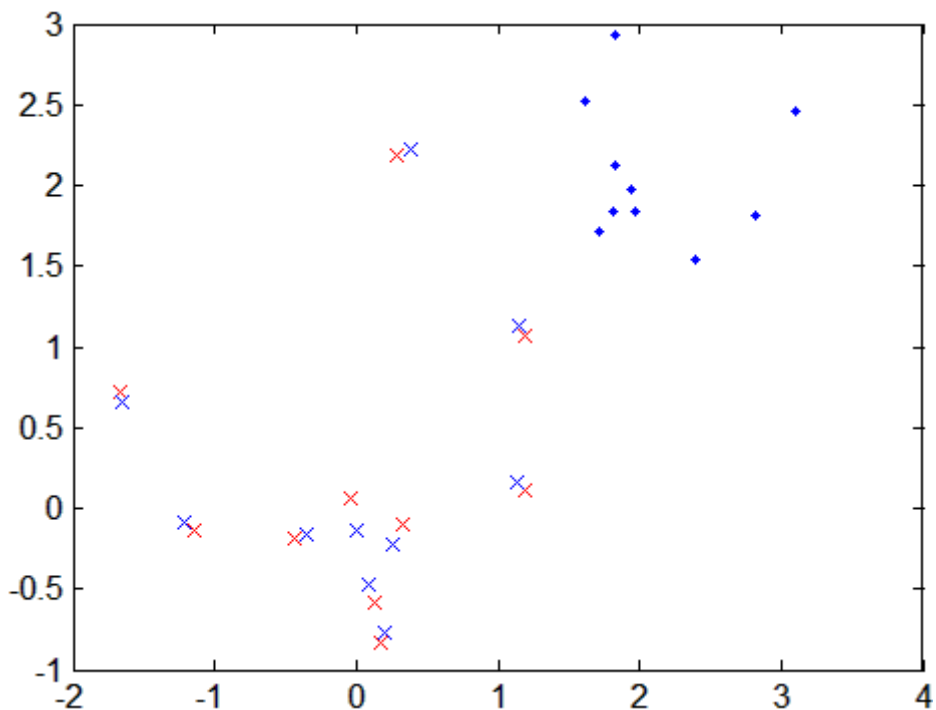
[...] = `procrustes(..., 'scaling', flag)`, when `flag` is `false`, allows you to compute the transformation without a scale component (that is, with `b` equal to 1). The default `flag` is `true`.

[...] = `procrustes(..., 'reflection', flag)`, when `flag` is `false`, allows you to compute the transformation without a reflection component (that is, with `det(T)` equal to 1). The default `flag` is `'best'`, which computes the best-fitting transformation, whether or not it includes a reflection component. A `flag` of `true` forces the transformation to be computed with a reflection component (that is, with `det(T)` equal to -1)

Examples

This example creates some random points in two dimensions, then rotates, scales, translates, and adds some noise to those points. It uses `procrustes` to conform `Y` to `X`, then plots the original `X` and `Y` with the transformed `Y`.

```
n = 10;
X = normrnd(0,1,[n 2]);
S = [0.5 -sqrt(3)/2; sqrt(3)/2 0.5];
Y = normrnd(0.5*X*S+2,0.05,n,2);
[d,Z,tr] = procrustes(X,Y);
plot(X(:,1),X(:,2),'rx',...
      Y(:,1),Y(:,2),'b.',...
      Z(:,1),Z(:,2),'bx');
```



References

[1] Kendall, David G. "A Survey of the Statistical Theory of Shape." *Statistical Science*. Vol. 4, No. 2, 1989, pp. 87–99.

[2] Bookstein, Fred L. *Morphometric Tools for Landmark Data*. Cambridge, UK: Cambridge University Press, 1991.

[3] Seber, G. A. F. *Multivariate Observations*. Hoboken, NJ: John Wiley & Sons, Inc., 1984.

See Also

`cmdscales` | `factoran`

Purpose Proximity matrix for data

Syntax `prox = proximity(B,X)`

Description `prox = proximity(B,X)` computes a numeric matrix of size Nobs-by-Nobs of proximities for data X , where Nobs is the number of observations (rows) in X . Proximity between any two observations in the input data is defined as a fraction of trees in the ensemble B for which these two observations land on the same leaf. This is a symmetric matrix with ones on the diagonal and off-diagonal elements ranging from 0 to 1.

TreeBagger.Proximity property

Purpose Proximity matrix for observations

Description The `Proximity` property is a numeric matrix of size `Nobs-by-Nobs`, where `Nobs` is the number of observations in the training data, containing measures of the proximity between observations. For any two observations, their proximity is defined as the fraction of trees for which these observations land on the same leaf. This is a symmetric matrix with 1s on the diagonal and off-diagonal elements ranging from 0 to 1.

See Also `CompactTreeBagger.proximity` | `classregtree.varimportance`

Purpose

Produce sequence of subtrees by pruning

Syntax

```
tree1 = prune(tree)
tree1 = prune(tree,Name,Value)
```

Description

`tree1 = prune(tree)` creates a copy of the classification tree `tree` with its optimal pruning sequence filled in.

`tree1 = prune(tree,Name,Value)` creates a pruned tree with additional options specified by one `Name,Value` pair argument. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Tips

- `tree1 = prune(tree)` returns the decision tree `tree1` that is the full, unpruned tree, but with optimal pruning information added. This is useful only if you created `tree` by pruning another tree, or by using the `ClassificationTree.fit` method with pruning set 'off'. If you plan to prune a tree multiple times along the optimal pruning sequence, it is more efficient to create the optimal pruning sequence first.

Input Arguments

tree

A classification tree created with `ClassificationTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

alpha

A numeric scalar. `prune` prunes `tree` to the specified value of the pruning cost.

level

ClassificationTree.prune

A numeric scalar from 0 (no pruning) to the largest pruning level of this tree `max(tree.PruneList)`. `prune` returns the tree pruned to this level.

nodes

A numeric vector with elements from 1 to `tree.NumNodes`. Any `tree` branch nodes listed in `nodes` become leaf nodes in `tree1`, unless their parent nodes are also pruned.

Output Arguments

tree1

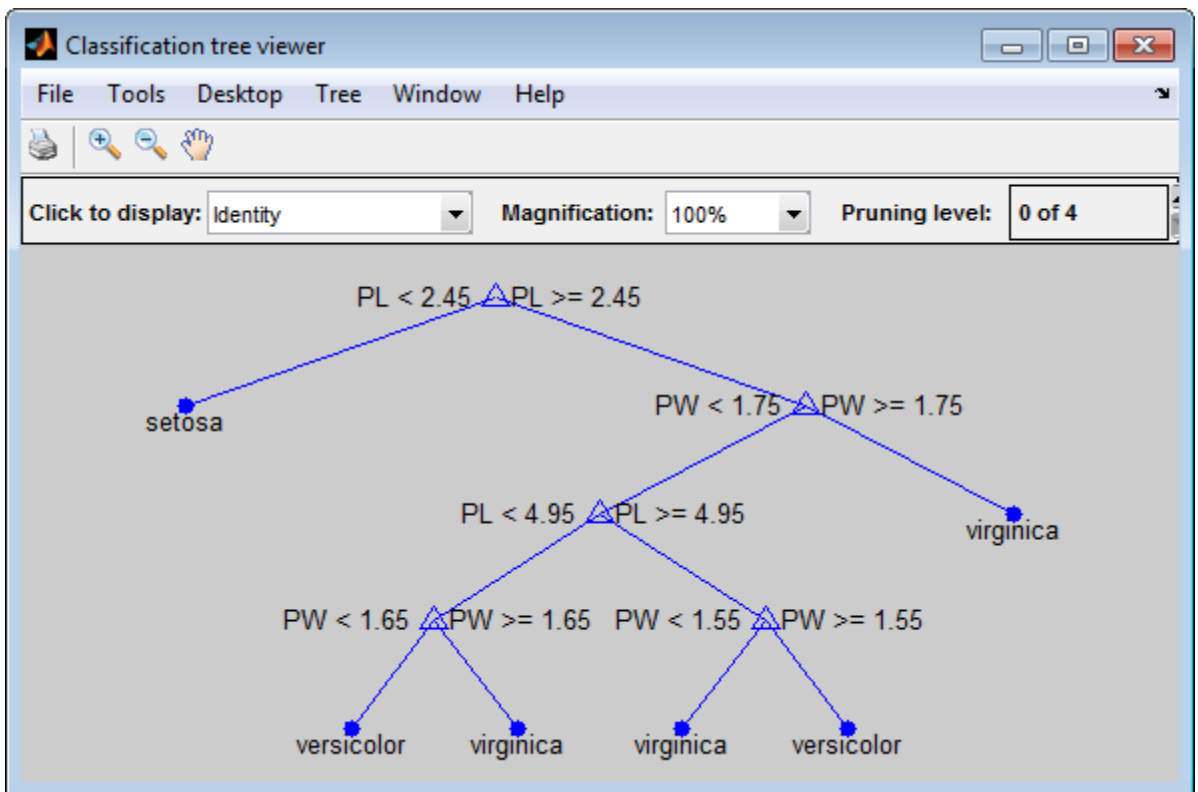
A classification tree.

Examples

Display a full tree for Fisher's iris data, as well as the next largest tree from the optimal pruning sequence:

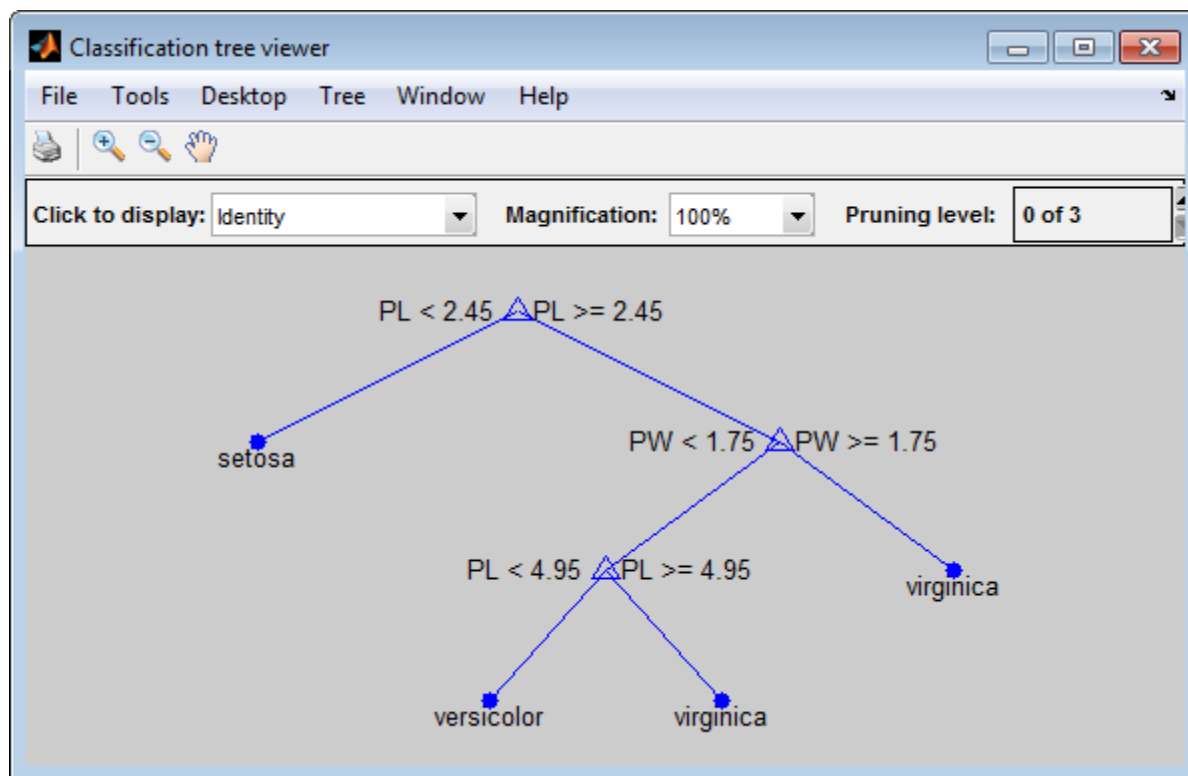
```
load fisheriris;
varnames = {'SL' 'SW' 'PL' 'PW'};
t1 = ClassificationTree.fit(meas,species,...
    'minparent',5,'predictorNames',varnames);
view(t1,'mode','graph');
```

ClassificationTree.prune



```
t2 = prune(t1,'level',1);  
view(t2,'mode','graph');
```

ClassificationTree.prune



See Also

ClassificationTree.fit

Purpose

Prune tree

Syntax

```
t2 = prune(t1, 'level', level)
t2 = prune(t1, 'nodes', nodes)
t2 = prune(t1)
```

Description

`t2 = prune(t1, 'level', level)` takes a decision tree `t1` and a pruning level `level`, and returns the decision tree `t2` pruned to that level. If `level` is 0, there is no pruning. Trees are pruned based on an optimal pruning scheme that first prunes branches giving less improvement in error cost.

`t2 = prune(t1, 'nodes', nodes)` prunes the nodes listed in the `nodes` vector from the tree. Any `t1` branch nodes listed in `nodes` become leaf nodes in `t2`, unless their parent nodes are also pruned. Use `view` to display the node numbers for any node you select.

`t2 = prune(t1)` returns the decision tree `t2` that is the full, unpruned `t1`, but with optimal pruning information added. This is useful only if `t1` is created by pruning another tree, or by using the `classregtree` function with the `'prune'` parameter set to `'off'`. If you plan to prune a tree multiple times along the optimal pruning sequence, it is more efficient to create the optimal pruning sequence first.

Pruning is the process of reducing a tree by turning some branch nodes into leaf nodes and removing the leaf nodes under the original branch.

Examples

Display the full tree for Fisher's iris data:

```
load fisheriris;

t1 = classregtree(meas, species, ...
                 'names', {'SL' 'SW' 'PL' 'PW'}, ...
                 'splitmin', 5)

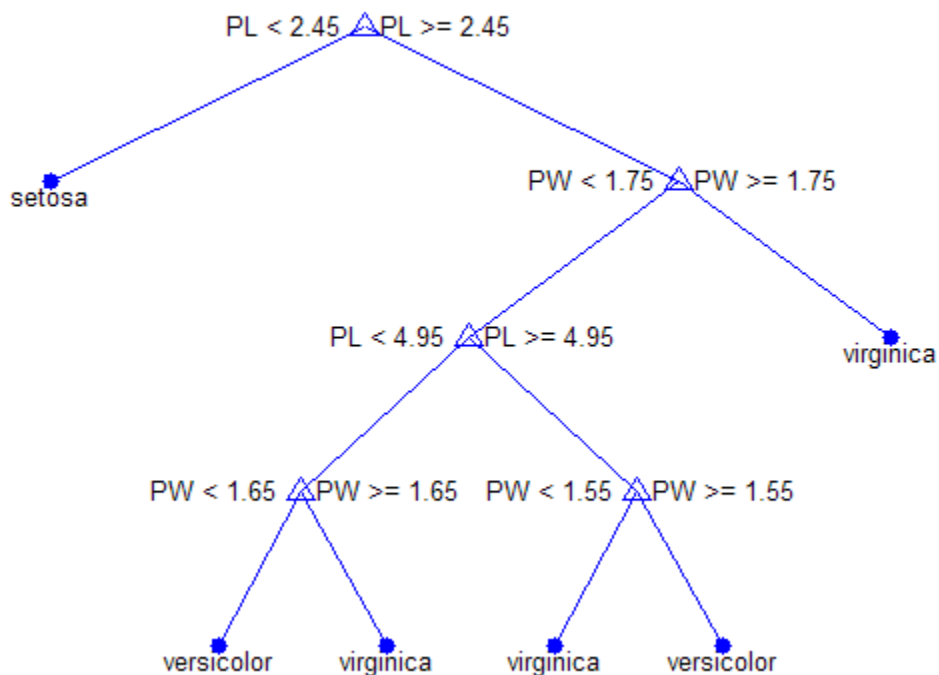
t1 =
Decision tree for classification
1 if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2 class = setosa
```

classregtree.prune

```
3 if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4 if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5 class = virginica
6 if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7 class = virginica
8 class = versicolor
9 class = virginica

view(t1)
```

Click to display: Magnification: Pruning level:



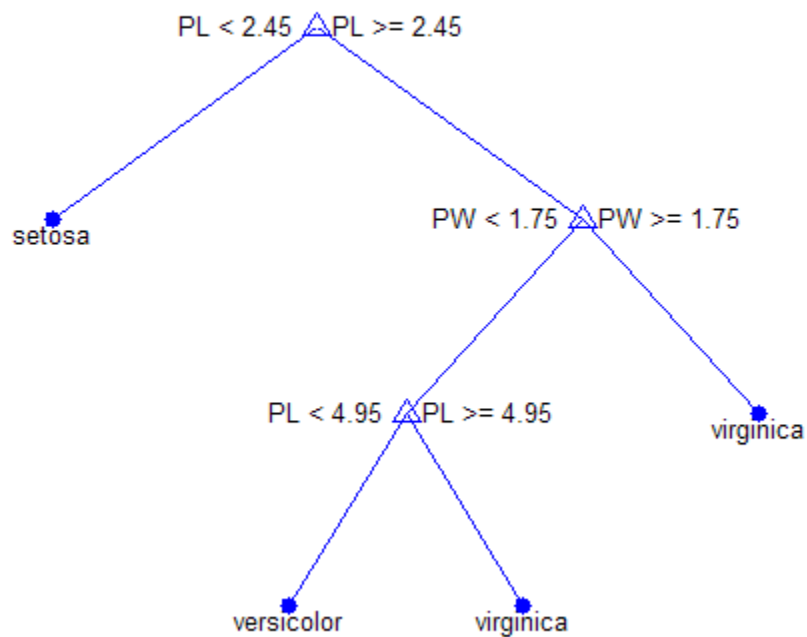
Display the next largest tree from the optimal pruning sequence:

```
t2 = prune(t1, 'level', 1)
t2 =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  class = versicolor
7  class = virginica

view(t2)
```

classregtree.prune

Click to display: Magnification: Pruning level:



References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

[classregtree](#) | [test](#) | [view](#)

Purpose

Produce sequence of subtrees by pruning

Syntax

```
tree1 = prune(tree)
tree1 = prune(tree,Name,Value)
```

Description

`tree1 = prune(tree)` creates a copy of the regression tree `tree` with its optimal pruning sequence filled in.

`tree1 = prune(tree,Name,Value)` creates a pruned tree with additional options specified by one `Name, Value` pair argument. You can specify several name-value pair arguments in any order as `Name1,Value1, ,NameN,ValueN`.

Tips

- `tree1 = prune(tree)` returns the decision tree `tree1` that is the full, unpruned tree, but with optimal pruning information added. This is useful only if you created `tree` by pruning another tree, or by using the `RegressionTree.fit` with pruning set 'off'. If you plan to prune a tree multiple times along the optimal pruning sequence, it is more efficient to create the optimal pruning sequence first.

Input Arguments**tree**

A regression tree created with `RegressionTree.fit`.

Name-Value Pair Arguments

Optional comma-separated pair of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify only one name-value pair argument.

alpha

A numeric scalar from 0 (no pruning) to 1 (prune to one node). Prunes to minimize the sum of (`alpha` times the number of leaf nodes) and a cost (mean squared error).

level

RegressionTree.prune

A numeric scalar from 0 (no pruning) to the largest pruning level of this tree `max(tree.PruneList)`. `prune` returns the tree pruned to this level.

nodes

A numeric vector with elements from 1 to `tree.NumNodes`. Any `tree` branch nodes listed in `nodes` become leaf nodes in `tree1`, unless their parent nodes are also pruned.

Output Arguments

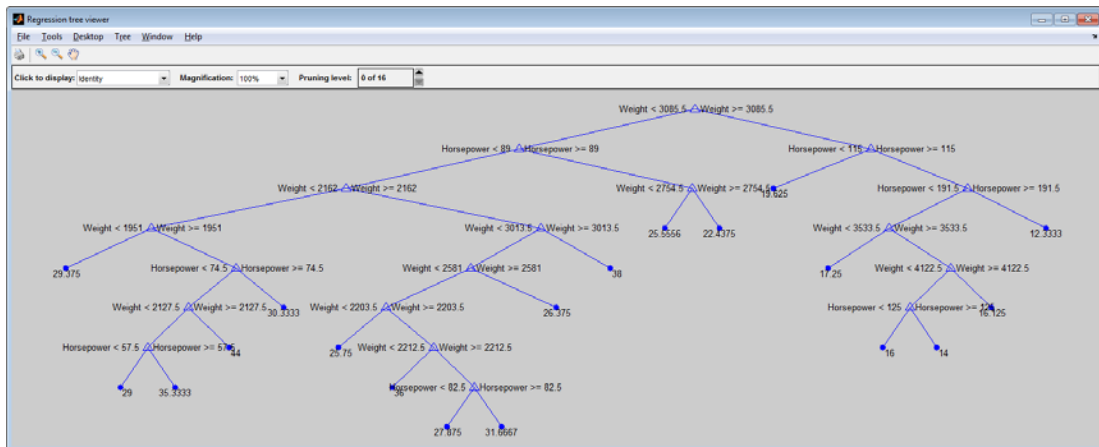
tree1

A regression tree.

Examples

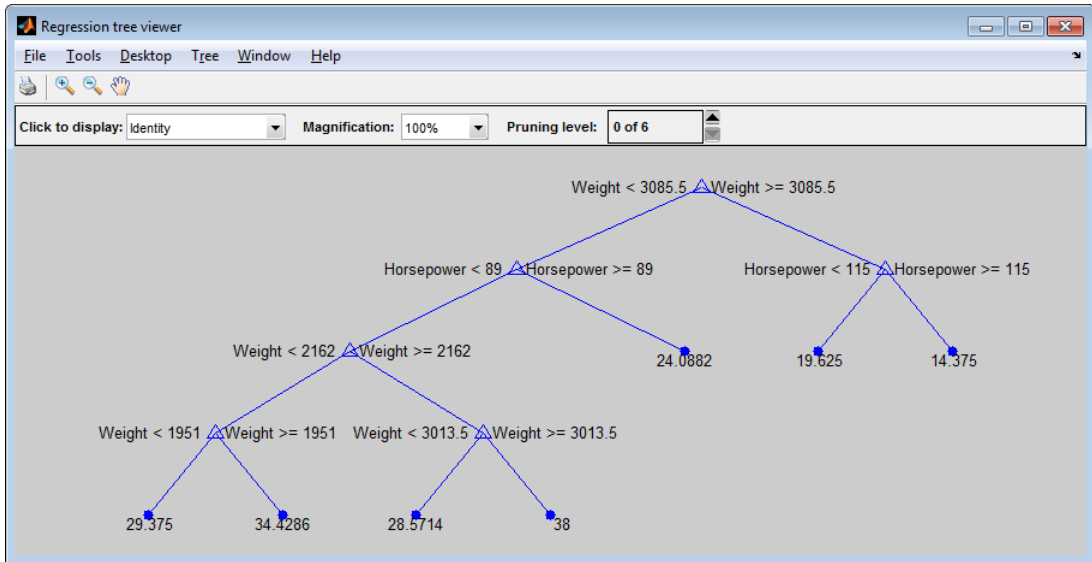
Display a full tree for the `carsmall` data, as well as the tree pruned to level 10:

```
load carsmall;
varnames = {'Weight' 'Horsepower'};
t1 = RegressionTree.fit([Weight Horsepower],MPG,...
    'predictorNames',varnames)
view(t1,'mode','graph');
```



```
t2 = prune(t1,'level',10);
```

```
view(t2, 'mode', 'graph');
```



See Also

`RegressionTree.fit`

TreeBagger.Prune property

Purpose Flag to prune trees

Description The Prune property is true if decision trees are pruned and false if they are not. Pruning decision trees is not recommended for ensembles. The default value is false.

See Also `classregtree.prune`

Purpose

Pruning levels for decision tree nodes

Syntax

P = prunelist(T)
P = prunelist(T,J)

Description

P = prunelist(T) returns an n -element numeric vector with the pruning levels in each node of the tree T, where n is the number of nodes. When you call `prune(T, 'level', level)`, nodes with the pruning levels below *level* are pruned, and nodes with the pruning levels greater or equal to *level* are not pruned.

P = prunelist(T,J) takes an array J of node numbers and returns the pruning levels for the specified nodes.

See Also

classregtree | numnodes

grandstream.grand

Purpose Generate quasi-random points from stream

Syntax
`x = grand(q)`
`X = grand(q,n)`

Description `x = grand(q)` returns the next value x in the quasi-random number stream q of the `grandstream` class. x is a 1-by- d vector, where d is the dimension of the stream. The command sets `q.State` to the index in the underlying point set of the next value to be returned.

`X = grand(q,n)` returns the next n values X in an n -by- d matrix.

Objects q of the `grandstream` class encapsulate properties of a specified quasi-random number stream. Values of the stream are not generated and stored in memory until q is accessed using `grand`.

Examples

Use `grandstream` to construct a 3-D Halton stream, based on a point set that skips the first 1000 values and then retains every 101st point:

```
q = grandstream('halton',3,'Skip',1e3,'Leap',1e2)
q =
    Halton quasi-random stream in 3 dimensions
    Point set properties:
        Skip : 1000
        Leap : 100
        ScrambleMethod : none
```

```
nextIdx = q.State
nextIdx =
     1
```

Use `grand` to generate two samples of size four:

```
X1 = grand(q,4)
X1 =
    0.0928    0.3475    0.0051
    0.6958    0.2035    0.2371
    0.3013    0.8496    0.4307
```



```
    0.9087    0.5629    0.6166
nextIdx = q.State
nextIdx =
    5

X2 = qrand(q,4)
X2 =
    0.2446    0.0238    0.8102
    0.5298    0.7540    0.0438
    0.3843    0.5112    0.2758
    0.8335    0.2245    0.4694
nextIdx = q.State
nextIdx =
    9
```

Use `reset` to reset the stream, then generate another sample:

```
reset(q)
nextIdx = q.State
nextIdx =
    1

X = qrand(q,4)
X =
    0.0928    0.3475    0.0051
    0.6958    0.2035    0.2371
    0.3013    0.8496    0.4307
    0.9087    0.5629    0.6166
```

See Also

[grandstream](#) | [reset](#)

grandset

Purpose	Quasi-random point sets	
Description	grandset is a base class that encapsulates a sequence of multi-dimensional quasi-random numbers. This base class is abstract and cannot be instantiated directly. Concrete subclasses include sobolset and haltonset.	
Construction	grandset	Abstract quasi-random point set class
Methods	disp	Display grandset object
	end	Last index in indexing expression for point set
	length	Length of point set
	ndims	Number of dimensions in matrix
	net	Generate quasi-random point set
	scramble	Scramble quasi-random point set
	size	Number of dimensions in matrix
	suboref	Subscripted reference for grandset
Properties	Dimensions	Number of dimensions
	Leap	Interval between points
	ScrambleMethod	Settings that control scrambling

Skip	Number of initial points to omit from sequence
Type	Name of sequence on which point set P is based

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

See Also

[haltonset](#) | [sobolset](#)

How To

- “Quasi-Random Point Sets” on page 6-16

grandset

Purpose Abstract quasi-random point set class

Description `grandset` is an abstract class, and you cannot create instances of it directly. You must use `haltonset` or `sobolset` to create a `grandset` object.

See Also `haltonset` | `sobolset`

Purpose	Quasi-random number streams	
Construction	grandstream	Construct quasi-random number stream
Methods	addlistener	Add listener for event
	delete	Delete handle object
	disp	Display grandstream object
	eq	Test handle equality
	findobj	Find objects matching specified conditions
	findprop	Find property of MATLAB handle object
	ge	Greater than or equal relation for handles
	gt	Greater than relation for handles
	isvalid	Test handle validity
	le	Less than or equal relation for handles
	lt	Less than relation for handles
	ne	Not equal relation for handles
	notify	Notify listeners of event
	grand	Generate quasi-random points from stream
	rand	Generate quasi-random points from stream
	reset	Reset state

grandstream

Properties

PointSet

Point set from which stream is drawn

State

Current state of the stream

Copy Semantics

Handle. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

Purpose Construct quasi-random number stream

Syntax

```
q = grandstream(type,d)
q = grandstream(type,d,prop1,val1,prop2,val2,...)
q = grandstream(p)
```

Description `q = grandstream(type,d)` constructs a *d*-dimensional quasi-random number stream *q* of the `grandstream` class, of type specified by the string *type*. *type* is either 'halton' or 'sobol', and *q* is based on a point set from either the `haltonset` class or `sobolset` class, respectively, with default property settings.

`q = grandstream(type,d,prop1,val1,prop2,val2,...)` specifies property name/value pairs for the point set on which the stream is based. Applicable properties depend on *type*.

`q = grandstream(p)` constructs a stream based on the specified point set *p*. *p* must be a point set from either the `haltonset` class or `sobolset` class.

Examples Construct a 3-D Halton stream, based on a point set that skips the first 1000 values and then retains every 101st point:

```
q = grandstream('halton',3,'Skip',1e3,'Leap',1e2)
q =
  Halton quasi-random stream in 3 dimensions
  Point set properties:
      Skip : 1000
      Leap : 100
  ScrambleMethod : none
```

```
nextIdx = q.State
nextIdx =
     1
```

Use `grand` to generate two samples of size four:

```
X1 = grand(q,4)
```

grandstream

```
X1 =  
    0.0928    0.3475    0.0051  
    0.6958    0.2035    0.2371  
    0.3013    0.8496    0.4307  
    0.9087    0.5629    0.6166  
nextIdx = q.State  
nextIdx =  
    5
```

```
X2 = grand(q,4)  
X2 =  
    0.2446    0.0238    0.8102  
    0.5298    0.7540    0.0438  
    0.3843    0.5112    0.2758  
    0.8335    0.2245    0.4694  
nextIdx = q.State  
nextIdx =  
    9
```

Use `reset` to reset the stream, and then generate another sample:

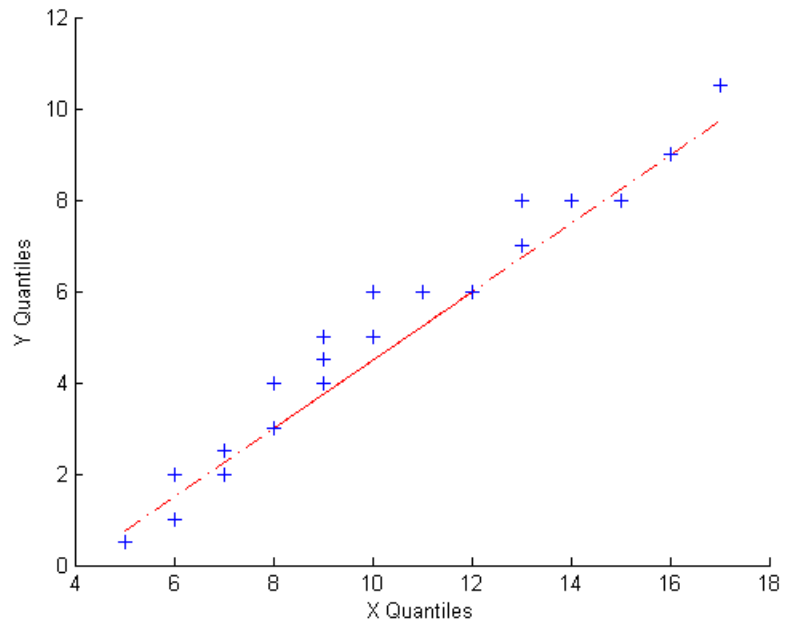
```
reset(q)  
nextIdx = q.State  
nextIdx =  
    1  
  
X = grand(q,4)  
X =  
    0.0928    0.3475    0.0051  
    0.6958    0.2035    0.2371  
    0.3013    0.8496    0.4307  
    0.9087    0.5629    0.6166
```

See Also

`haltonset` | `grand` | `reset` | `sobolset`

Purpose	Quantile-quantile plot
Syntax	<pre>qqplot(X) qqplot(X,Y) qqplot(X,PD) qqplot(X,Y,pvec) h = qqplot(X,Y,pvec)</pre>
Description	<p><code>qqplot(X)</code> displays a quantile-quantile plot of the sample quantiles of X versus theoretical quantiles from a normal distribution. If the distribution of X is normal, the plot will be close to linear.</p> <p><code>qqplot(X,Y)</code> displays a quantile-quantile plot of two samples. If the samples do come from the same distribution, the plot will be linear.</p> <p><code>qqplot(X,PD)</code> makes an empirical quantile-quantile plot of the quantiles of the data in the vector X versus the quantiles of the distribution specified by PD, a <code>ProbDist</code> object of the <code>ProbDistUnivParam</code> class or <code>ProbDistUnivKernel</code> class.</p> <p>For matrix X and Y, <code>qqplot</code> displays a separate line for each pair of columns. The plotted quantiles are the quantiles of the smaller data set.</p> <p>The plot has the sample data displayed with the plot symbol '+'. Superimposed on the plot is a line joining the first and third quartiles of each distribution (this is a robust linear fit of the order statistics of the two samples). This line is extrapolated out to the ends of the sample to help evaluate the linearity of the data.</p> <p>Use <code>qqplot(X,Y,pvec)</code> to specify the quantiles in the vector <code>pvec</code>.</p> <p><code>h = qqplot(X,Y,pvec)</code> returns handles to the lines in <code>h</code>.</p>
Examples	<p>The following example shows a quantile-quantile plot of two samples from Poisson distributions. The solid line joins the first and third quartiles. The dashed line extrapolates the solid line.</p> <pre>x = poissrnd(10,50,1); y = poissrnd(5,100,1); qqplot(x,y);</pre>

qqplot



How To

- normplot

Purpose

Quantiles of a data set

Syntax

`Y = quantile(X,p)`
`Y = quantile(X,p,dim)`

`Y = quantile(X,N)`
`Y = quantile(X,N,dim)`

Description

`Y = quantile(X,p)` returns quantiles of the values in data vector or matrix `X` for the cumulative probability or probabilities `p` in the interval `[0,1]`.

- If `X` is a vector, then `Y` is a scalar or a vector having the same length as `p`.
- If `X` is a matrix, then `Y` is a row vector or a matrix where the number of rows of `Y` is equal to the length of `p`.
- For multidimensional arrays, `quantile` operates along the first nonsingleton dimension of `X`.

`Y = quantile(X,p,dim)` returns quantiles along dimension `dim`.

`Y = quantile(X,N)` returns quantiles for `N` evenly spaced cumulative probabilities ($1/(N+1)$, $2/(N+1)$, ..., $N/(N+1)$) for integer $N > 1$.

- If `X` is a vector, then `Y` is a scalar or a vector with length `N`.
- If `X` is a matrix, then `Y` is a matrix where the number of rows of `Y` is equal to `N`.
- For multidimensional arrays, `quantile` operates along the first nonsingleton dimension of `X`.

`Y = quantile(X,N,dim)` returns quantiles at the `N` evenly-spaced cumulative probabilities ($1/(N+1)$, $2/(N+1)$, ..., $N/(N+1)$) for integer $N > 1$ along dimension `dim`.

quantile

Input Arguments

X - Input data

vector | array

Input data, specified as a vector or array.

Data Types

double | single

p - Cumulative probabilities

scalar | vector

Cumulative probabilities, for which to compute the quantiles, specified as a scalar or vector of scalars from 0 to 1.

Example: 0.3

Example: [0.25, 0.5, 0.75]

Example: (0:0.25:1)

Data Types

double | single

N - Number of quantiles

positive integer

Number of quantiles to compute, specified as a positive integer. `quantile` returns N quantiles that divide the data set into evenly distributed N+1 segments.

Data Types

double | single

dim - Dimension

1 (default) | positive integer

Dimension along which the quantiles of a matrix X are required, specified as a positive integer. For example, for a matrix X, when `dim = 1`, `quantile` returns the quantile(s) of the columns of X and when `dim = 2`, `quantile` returns the quantile(s) of the rows of X. For a multidimensional array X, the length of the `dim`th dimension of Y is same as length of p.

Output Arguments

Y - Quantiles

scalar | array

Quantiles of a data vector or matrix, returned as a scalar or array for one or multiple values of cumulative probabilities.

- If X is a vector, then Y is a scalar or a vector with the same length as the number of quantiles required (N or $\text{length}(p)$). $Y(i)$ contains the $p(i)$ quantile.
- If X is a matrix, then Y is a vector or a matrix with the length of dimth dimension equal to the number of quantiles required (N or $\text{length}(p)$). When $\text{dim} = 1$, for example, the i th row of Y contains the $p(i)$ quantiles of columns of X .
- If X is an array of dimension d , then Y is an array with the length of dimth dimension equal to the number of quantiles required (N or $\text{length}(p)$).

Definitions

Multidimensional Array

A *multidimensional array* is an array with more than two dimensions. For example, if X is a 1-by-3-by-4 array, then X is a 3-D array.

First Nonsingleton Dimension

A *first nonsingleton dimension* is the first dimension of an array whose size is not equal to 1. For example, if X is a 1-by-2-by-3-by-4 array, then the second dimension is the first nonsingleton dimension of X .

Linear Interpolation

Linear interpolation uses linear polynomials to find $y_i = f(x_i)$, the values of the underlying function $Y = f(X)$ at the points in the vector or array x . Given the data points (x_1, y_1) and (x_2, y_2) , where $y_1 = f(x_1)$ and $y_2 = f(x_2)$, linear interpolation finds $y = f(x)$ for a given x between x_1 and x_2 as follows:

$$y = f(x) = y_1 + \frac{(x - x_1)}{(x_2 - x_1)}(y_2 - y_1).$$

quantile

Similarly, if the $1.5/n$ quantile is $y_{1.5/n}$ and the $2.5/n$ quantile is $y_{2.5/n}$, then linear interpolation finds the $2.3/n$ quantile $y_{2.3/n}$ as

$$y_{\frac{2.3}{n}} = y_{\frac{1.5}{n}} + \frac{\left(\frac{2.3}{n} - \frac{1.5}{n}\right)}{\left(\frac{2.5}{n} - \frac{1.5}{n}\right)} \left(y_{\frac{2.5}{n}} - y_{\frac{1.5}{n}}\right).$$

Algorithms

For an n -element vector X , `quantile` computes quantiles as follows:

- 1 The sorted values in X are taken as the $(0.5/n)$, $(1.5/n)$, ..., $([n - 0.5]/n)$ quantiles. For example:
 - For a data vector of five elements such as $\{6, 3, 2, 10, 1\}$, the sorted elements $\{1, 2, 3, 6, 10\}$ respectively correspond to the 0.1, 0.3, 0.5, 0.7, 0.9 quantiles.
 - For a data vector of six elements such as $\{6, 3, 2, 10, 8, 1\}$, the sorted elements $\{1, 2, 3, 6, 8, 10\}$ respectively correspond to the $(0.5/6)$, $(1.5/6)$, $(2.5/6)$, $(3.5/6)$, $(4.5/6)$, $(5.5/6)$ quantiles.
- 2 `quantile` uses Linear interpolation to compute quantiles for probabilities between $(0.5/n)$ and $([n - 0.5]/n)$.
- 3 For the quantiles corresponding to the probabilities outside that range, `quantile` assigns the minimum or maximum values in X .

`quantile` treats NaNs as missing values and removes them.

Examples

Quantiles for Given Probabilities

Calculate the quantiles of a data set for specified probabilities.

Generate a data set of size 10.

```
rng('default'); % for reproducibility
x = normrnd(0,1,1,10)
```

```
x =
    0.5377    1.8339   -2.2588    0.8622    0.3188   -1.3077   -0.4336
```

Calculate the 0.3 quantile.

```
y = quantile(x,0.30)
```

```
y =
   -0.0574
```

Calculate the quantiles for the cumulative probabilities 0.025, 0.25, 0.5, 0.75, and 0.975.

```
y = quantile(x,[0.025 0.25 0.50 0.75 0.975])
```

```
y =
   -2.2588   -0.4336    0.4401    1.8339    3.5784
```

Quantiles of a Matrix for Given Probabilities

Calculate the quantiles along the columns and rows of a data matrix for specified probabilities.

Generate a 4-by-6 data matrix.

```
rng('default'); % for reproducibility
X = normrnd(0,1,4,6)
```

```
X =
    0.5377    0.3188    3.5784    0.7254   -0.1241    0.6715
    1.8339   -1.3077    2.7694   -0.0631    1.4897   -1.2075
   -2.2588   -0.4336   -1.3499    0.7147    1.4090    0.7172
    0.8622    0.3426    3.0349   -0.2050    1.4172    1.6302
```

Calculate the 0.3 quantile for each column of X (dim = 1).

```
y = quantile(x,0.3,1)
```

quantile

```
y =  
    -0.3013    -0.6958     1.5336    -0.1056     0.9491     0.1078
```

`quantile` returns a row vector `y` when calculating one quantile for each column of a matrix. For example, `-0.3013` is the 0.3 quantile of the first column of `X` with elements `(0.5377, 1.8339, -2.2588, 0.8622)`. `y = quantile(X,0.3)` returns the same answer because the default value of `dim` is 1.

Calculate the 0.3 quantile for each row of `X` (`dim = 2`).

```
y = quantile(x,0.3,2)
```

```
y =  
    0.3844  
   -0.8642  
   -1.0750  
    0.4985
```

`quantile` returns a column vector `y` when calculating one quantile for each row of a matrix. For example `0.3844` is the 0.3 quantile of the first row of `X` with elements `(0.5377, 0.3188, 3.5784, 0.7254, -0.1241, 0.6715)`.

Quantiles for N Evenly Spaced Cumulative Probabilities

Calculate the quantiles of a data set for a given number of quantiles.

Generate a data set of size 10.

```
rng('default'); % for reproducibility  
x = normrnd(0,1,1,10)
```

```
x =  
    0.5377     1.8339    -2.2588     0.8622     0.3188    -1.3077    -0.4336
```

Calculate four evenly spaced quantiles.

```
y = quantile(x,4)
```



```
y =
    -0.8706    0.3307    0.6999    2.3017
```

Using `y = quantile(x,[0.2,0.4,0.6,0.8])` is another way to return the four evenly spaced quantiles.

Quantiles of a Matrix for Given Number of Quantiles

Calculate the N evenly spaced quantiles along the columns and rows of a data matrix.

Generate a 6-by-10 data matrix.

```
rng('default'); % for reproducibility
X = unidrnd(10,6,7)
```

```
X =
     9     3    10     8     7     8     7
    10     6     5    10     8     1     4
     2    10     9     7     8     3    10
    10    10     2     1     4     1     1
     7     2     5     9     7     1     5
     1    10    10    10     2     9     4
```

Calculate three evenly spaced quantiles for each column of X (`dim = 1`).

```
y = quantile(X,3,1)
```

```
y =
    2.0000    3.0000    5.0000    7.0000    4.0000    1.0000    4.0000
    8.0000    8.0000    7.0000    8.5000    7.0000    2.0000    4.5000
   10.0000   10.0000   10.0000   10.0000    8.0000    8.0000    7.0000
```

Each column of matrix `y` corresponds to the three evenly spaced quantiles of each column of matrix `X`. For example, the first column of `y` with elements (2, 8, 10) has the quantiles for the first column of `X`

quantile

with elements (9, 10, 2, 10, 7, 1). `y = quantile(X,3)` returns the same answer because the default value of `dim` is 1.

Calculate three evenly spaced quantiles for each row of `X` (`dim = 2`).

```
y = quantile(X,3,2)
```

```
y =
```

```
    7.0000    8.0000    8.7500
    4.2500    6.0000    9.5000
    4.0000    8.0000    9.7500
    1.0000    2.0000    8.5000
    2.7500    5.0000    7.0000
    2.5000    9.0000   10.0000
```

Each row of matrix `y` corresponds to the three evenly spaced quantiles of each row of matrix `X`. For example, the first row of `y` with elements (7, 8, 8.75) has the quantiles for the first column of `X` with elements (9, 3, 10, 8, 7, 8, 7).

Median and Quartiles for Even Number of Data Elements

Find median and quartiles of a vector, `x`, with even number of elements.

Enter the data.

```
x = [2 5 6 10 11 13]
```

```
x =
```

```
    2    5    6   10   11   13
```

Calculate the median of `x`.

```
y = quantile(x,0.50)
```

```
y =
```

```
    8
```

Calculate the quartiles of x .

```
y = quantile(x,[0.25, 0.5, 0.75])
```

```
y =
     5     8    11
```

Using `y = quantile(x,3)` is another way to compute the quartiles of x .

These results might be different than the textbook definitions because `quantile` uses linear interpolation to find the median and quartiles.

Median and Quartiles for Odd Number of Data Elements

Find median and quartiles of a vector, x , with odd number of elements.

Enter the data.

```
x = [2 4 6 8 10 12 14]
```

```
x =
     2     4     6     8    10    12    14
```

Find the median of x .

```
y = quantile(x,0.50)
```

```
y =
     8
```

Find the quartiles of x .

```
y = quantile(x,[0.25, 0.5, 0.75])
```

```
y =
  4.5000   8.0000  11.5000
```

Using `y = quantile(x,3)` is another way to compute the quartiles of x .

quantile

These results might be different than the textbook definitions because `quantile` uses linear interpolation to find the median and quartiles.

See Also

`iqr` | `median` | `prctile`

Concepts

- “Quantiles and Percentiles” on page 3-7

Purpose Generate quasi-random points from stream

Syntax

```
rand
rand(q,n)
rand(q)
rand(q,m,n)
rand(q,[m,n])
rand(q,m,n,p,...)
rand(q,[m,n,p,...])
```

Description

rand returns a matrix of quasi-random values and is intended to allow objects of the `grandstream` class to be used in code that contains calls to the `rand` method of the MATLAB pseudo-random `randstream` class. Due to the multidimensional nature of quasi-random numbers, only some syntaxes of `rand` are supported by the `grandstream` class.

`rand(q,n)` returns an n -by- n matrix only when n is equal to the number of dimensions. Any other value of n produces an error.

`rand(q)` returns a scalar only when the stream is in one dimension. Having more than one dimension in `q` produces an error.

`rand(q,m,n)` or `rand(q,[m,n])` returns an m -by- n matrix only when n is equal to the number of dimensions in the stream. Any other value of n produces an error.

`rand(q,m,n,p,...)` or `rand(q,[m,n,p,...])` produces an error unless p and all following dimensions sizes are equal to one.

Examples Generate the first 256 points from a 5-D Sobol sequence:

```
q = grandstream('sobol',5);
X = rand(q,256,5);
```

See Also `grandstream` | `grand` | `rand`

randg

Purpose Gamma random numbers with unit scale

Syntax

```
Y = randg
Y = randg(A)
Y = randg(A,m)
Y = randg(A,m,n,p,...)
Y = randg(A,[m,n,p,...])
```

Description

`Y = randg` returns a scalar random value chosen from a gamma distribution with unit scale and shape.

`Y = randg(A)` returns a matrix of random values chosen from gamma distributions with unit scale. `Y` is the same size as `A`, and `randg` generates each element of `Y` using a shape parameter equal to the corresponding element of `A`.

`Y = randg(A,m)` returns an `m`-by-`m` matrix of random values chosen from gamma distributions with shape parameters `A`. `A` is either an `m`-by-`m` matrix or a scalar. If `A` is a scalar, `randg` uses that single shape parameter value to generate all elements of `Y`.

`Y = randg(A,m,n,p,...)` or `Y = randg(A,[m,n,p,...])` returns an `m`-by-`n`-by-`p`-by-`...` array of random values chosen from gamma distributions with shape parameters `A`. `A` is either an `m`-by-`n`-by-`p`-by-`...` array or a scalar.

`randg` produces pseudo-random numbers using the MATLAB functions `rand` and `randn`. The sequence of numbers generated is determined by the settings of the uniform random number generator that underlies `rand` and `randn`. Control that shared random number generator using `rng`. See the `rng` documentation for more information.

Note To generate gamma random numbers and specify both the scale and shape parameters, you should call `gamrnd`.

Examples

Example 1

Generate a 100-by-1 array of values drawn from a gamma distribution with shape parameter 3.

```
r = randg(3,100,1);
```

Example 2

Generate a 100-by-2 array of values drawn from gamma distributions with shape parameters 3 and 2.

```
A = [ones(100,1)*3,ones(100,1)*2];  
r = randg(A,[100,2]);
```

Example 3

To create reproducible output from randg, reset the random number generator used by rand and randn to its default startup settings. This way randg produces the same random numbers as if you restarted MATLAB.

```
rng('default')  
randg(3,1,5)
```

```
ans =
```

```
6.9223    4.3369    1.0505    3.2662    11.3269
```

Example 4

Save the settings for the random number generator used by rand and randn, generate 5 values from randg, restore the settings, and repeat those values.

```
s = rng; % Obtain the current state of the random stream  
r1 = randg(10,1,5)
```

```
r1 =
```

```
9.4719    9.0433    15.0774    14.7763    6.3775
```

randg

```
rng(s); % Reset the stream to the previous state  
r2 = randg(10,1,5)
```

```
r2 =
```

```
    9.4719    9.0433   15.0774   14.7763    6.3775
```

r2 contains exactly the same values as r1.

Example 5

Reinitialize the random number generator used by `rand` and `randn` with a seed based on the current time. `randg` returns different values each time you do this. Note that it is usually not necessary to do this more than once per MATLAB session.

```
rng('shuffle');  
randg(2,1,5);
```

References

[1] Marsaglia, G., and W. W. Tsang. "A Simple Method for Generating Gamma Variables." *ACM Transactions on Mathematical Software*. Vol. 26, 2000, pp. 363–372.

See Also

`gamrnd`

Purpose

Random numbers

Syntax

```

Y = random(name,A)
Y = random(name,A,B)
Y = random(name,A,B,C)
Y = random(name,A,m,n,...)
Y = random(name,A,[m,n,...])
Y = random(name,A,B,m,n,...)
Y = random(name,A,B,[m,n,...])
Y = random(name,A,B,C,m,n,...)
Y = random(name,A,B,C,[m,n,...])

```

Description

`Y = random(name,A)` where `name` is the name of a distribution that takes a single parameter, returns random numbers `Y` from the one-parameter family of distributions specified by `name`. Parameter values for the distribution are given in `A`.

`Y` is the same size as `A`.

`Y = random(name,A,B)` returns random numbers `Y` from a two-parameter family of distributions. Parameter values for the distribution are given in `A` and `B`.

If `A` and `B` are arrays, they must be the same size. If either `A` or `B` are scalars, they are expanded to constant matrices of the same size.

`Y = random(name,A,B,C)` returns random numbers `Y` from a three-parameter family of distributions. Parameter values for the distribution are given in `A`, `B`, and `C`.

If `A`, `B`, and `C` are arrays, they must be the same size. If any of `A`, `B`, or `C` are scalars, they are expanded to constant matrices of the same size.

`Y = random(name,A,m,n,...)` or `Y = random(name,A,[m,n,...])` returns an `m`-by-`n`-by... matrix of random numbers.

Similarly, `Y = random(name,A,B,m,n,...)` or `Y = random(name,A,B,[m,n,...])` returns an `m`-by-`n`-by... matrix of random numbers for distributions that require two parameters. `Y = random(name,A,B,C,m,n,...)` or `Y =`

random

`random(name, A, B, C, [m, n, ...])` returns an m-by-n-by... matrix of random numbers for distributions that require three parameters.

If any of A, B, or C are arrays, then the specified dimensions must match the common dimensions of A, B, and C after any necessary scalar expansion.

The following table denotes the acceptable strings for name, as well as the parameters for that distribution:

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'beta' or 'Beta'	“Beta Distribution” on page B-4	a	b	—
'bino' or 'Binomial'	“Binomial Distribution” on page B-7	n: number of trials	p: probability of success for each trial	—
'birnbaumsaunders' or 'Birnbaum-Saunders'	“Birnbaum-Saunders Distribution” on page B-10	α	γ	—
'burr' or 'Burr'	“Burr Type XII Distribution” on page B-12	α : scale parameter	c: shape parameter	k: shape parameter
'chi2' or 'Chisquare'	“Chi-Square Distribution” on page B-25	ν : degrees of freedom	—	—
'exp' or 'Exponential'	“Exponential Distribution” on page B-29	μ : mean	—	—
'ev' or 'Extreme Value'	“Extreme Value Distribution” on page B-32	μ : location parameter	σ : scale parameter	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'f' or 'F'	“F Distribution” on page B-38	v1: numerator degrees of freedom	v2: denominator degrees of freedom	—
'gam' or 'Gamma'	“Gamma Distribution” on page B-40	a: shape parameter	b: scale parameter	—
'gev' or 'Generalized Extreme Value'	“Generalized Extreme Value Distribution” on page B-45	k: shape parameter	σ : scale parameter	μ : location parameter
'gp' or 'Generalized Pareto'	“Generalized Pareto Distribution” on page B-50	k: tail index (shape) parameter	σ : scale parameter	μ : threshold (location) parameter
'geo' or 'Geometric'	“Geometric Distribution” on page B-54	p: probability parameter	—	—
'hyge' or 'Hypergeometric'	“Hypergeometric Distribution” on page B-56	M: size of the population	K: number of items with the desired characteristic in the population	n: number of samples drawn
'inversegaussian'	“Inverse Gaussian Distribution” on page B-58	μ	λ	—
'logistic'	“Logistic Distribution” on page B-62	μ	σ	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'loglogistic'	“Loglogistic Distribution” on page B-63	μ	σ	—
'logn' or 'Lognormal'	“Lognormal Distribution” on page B-64	μ	σ	—
'nakagami'	“Nakagami Distribution” on page B-83	μ	ω	—
'nbin' or 'Negative Binomial'	“Negative Binomial Distribution” on page B-85	r: number of successes	p: probability of success in a single trial	—
'ncf' or 'Noncentral F'	“Noncentral F Distribution” on page B-91	v1: numerator degrees of freedom	v2: denominator degrees of freedom	δ : noncentrality parameter
'nct' or 'Noncentral t'	“Noncentral t Distribution” on page B-93	v: degrees of freedom	δ : noncentrality parameter	—
'ncx2' or 'Noncentral Chi-square'	“Noncentral Chi-Square Distribution” on page B-89	v: degrees of freedom	δ : noncentrality parameter	—
'norm' or 'Normal'	“Normal Distribution” on page B-96	μ : mean	σ : standard deviation	—
'poiss' or 'Poisson'	“Poisson Distribution” on page B-102	λ : mean	—	—

name	Distribution	Input Parameter A	Input Parameter B	Input Parameter C
'rayl' or 'Rayleigh'	“Rayleigh Distribution” on page B-104	b: scale parameter	—	—
'rician'	“Rician Distribution” on page B-106	s: noncentrality parameter	σ : scale parameter	—
't' or 'T'	“Student’s t Distribution” on page B-108	ν : degrees of freedom	—	—
'tlocationscale'	“t Location-Scale Distribution” on page B-110	μ : location parameter	σ : scale parameter	ν : shape parameter
'unif' or 'Uniform'	“Uniform Distribution (Continuous)” on page B-112	a: lower endpoint (minimum)	b: upper endpoint (maximum)	—
'unid' or 'Discrete Uniform'	“Uniform Distribution (Discrete)” on page B-114	N: maximum observable value	—	—
'wbl' or 'Weibull'	“Weibull Distribution” on page B-116	a: scale parameter	b: shape parameter	—

Examples

Generate a 2-by-4 array of random values from the normal distribution with mean 0 and standard deviation 1:

```
x1 = random('Normal',0,1,2,4)
x1 =
```

random

```
1.1650  0.0751  -0.6965  0.0591
0.6268  0.3516  1.6961  1.7971
```

The order of the parameters is the same as for `normrnd`.

Generate a single random value from Poisson distributions with rate parameters 1, 2, ..., 6, respectively:

```
x2 = random('Poisson',1:6,1,6)
```

```
x2 =
```

```
0  0  1  2  5  7
```

See Also

[cdf](#) | [pdf](#) | [icdf](#) | [mle](#)

Purpose

Simulate responses for generalized linear regression model

Syntax

```
ysim = random mdl,Xnew  
ysim = random mdl,Xnew,Name,Value
```

Description

`ysim = random(mdl,Xnew)` simulates responses from the `mdl` generalized linear model to the data in `Xnew`.

`ysim = random(mdl,Xnew,Name,Value)` simulates responses with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments**mdl**

Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

Xnew

Points at which `mdl` predicts responses.

- If `Xnew` is a dataset array, it must contain the predictor names in `mdl`.
- If `Xnew` is a numeric matrix, it must have the same number of variables (columns) as was used to create `mdl`. Furthermore, all variables used in creating `mdl` must be numeric.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

BinomialSize

GeneralizedLinearModel.random

The value of the binomial n parameter for each row in the training data. `BinomialSize` can be a vector the same length as `Xnew`, or a scalar that applies to each row. The default value 1 produces `ysim` values that are predicted proportions. Use `BinomialSize` only if `mdl` is fit to a binomial distribution.

Default: 1

Offset

Value of the offset for each row in `Xnew`. `Offset` can be a vector the same length as `Xnew`, or a scalar that applies to each row. The offset is used as an additional predictor with a coefficient value fixed at 1. In other words, if `b` is the fitted coefficient vector, and `link` is the link function,

$$\text{link}(\text{ysim}) = \text{Offset} + \text{Xnew} * \text{b}.$$

Default: `zeros(size(Xnew,1))`

Output Arguments

`ysim`

Vector of simulated values at `Xnew`. `random` generates `ysim` using random values with mean given by the fitted model, and with the distribution used in `mdl`. The values in `ysim` are independent conditional on the predictors. For binomial and Poisson fits, `random` generates `ysim` with the specified distribution with no adjustment for any estimated dispersion.

Examples

Generalized Linear Model Simulation

Create a generalized linear model, and simulate its response to new data.

Generate artificial data for the model, Poisson random numbers with one underlying predictors `X`.

```
rng('default') % reproducible
```



```
X = rand(20,1);  
mu = exp(1 + 2*X);  
y = poissrnd(mu);
```

Create a generalized linear regression model of Poisson data.

```
mdl = GeneralizedLinearModel.fit(X,y,...  
    'y ~ x1','distr','poisson');
```

Create points for prediction.

```
Xnew = (0:.05:1)';
```

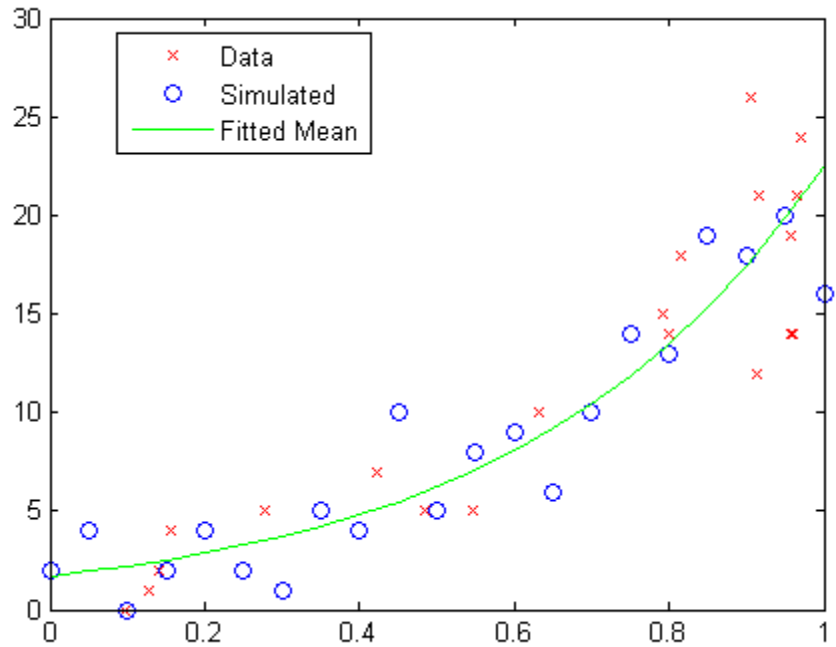
Simulate responses at the new points.

```
ysim = random(mdl,Xnew);
```

Plot the simulated values along with the original values.

```
plot(X,y,'rx',Xnew,ysim,'bo',...  
    Xnew,feval(mdl,Xnew),'g-')  
legend('Data','Simulated','Fitted Mean',...  
    'Location','best')
```

GeneralizedLinearModel.random



Alternatives

For predictions without random noise, use `predict` or `feval`.

See Also

`GeneralizedLinearModel` | `predict` |

Related Examples

- “random” on page 9-168

Concepts

- “Generalized Linear Models” on page 9-141

Purpose Random numbers from Gaussian mixture distribution

Syntax

```
y = random(obj)
Y = random(obj,n)
[Y,idx] = random(obj,n)
```

Description `y = random(obj)` generates a 1-by- d vector y drawn at random from the d -dimensional Gaussian mixture distribution defined by `obj`. `obj` is an object created by `gmdistribution` or `fit`.

`Y = random(obj,n)` generates an n -by- d matrix Y of n d -dimensional random samples.

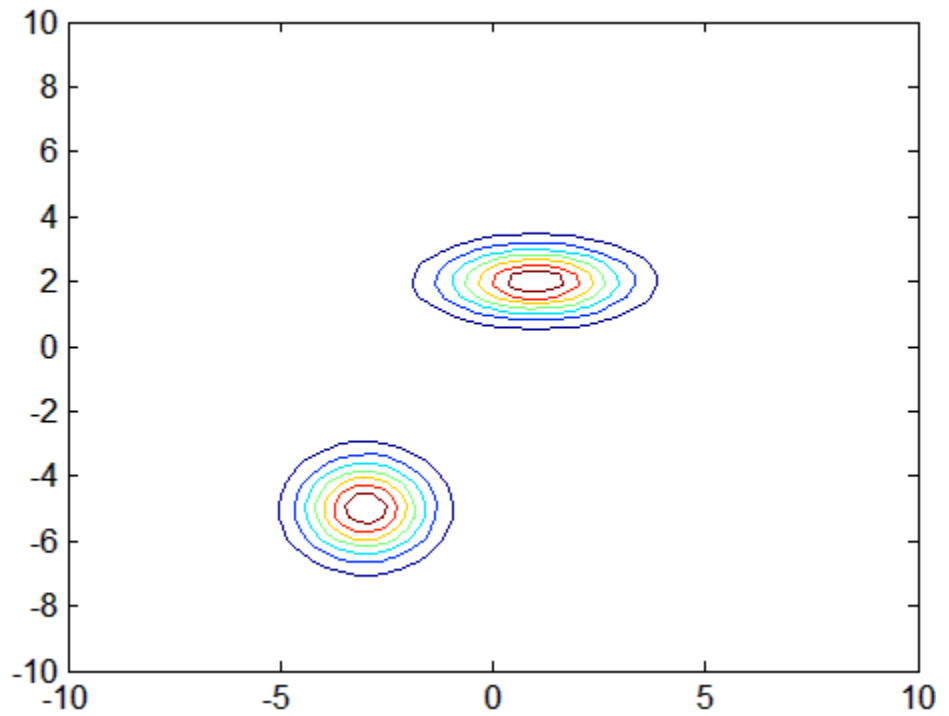
`[Y,idx] = random(obj,n)` also returns an n -by-1 vector `idx`, where `idx(I)` is the index of the component used to generate $Y(I,:)$.

Examples Create a `gmdistribution` object defining a two-component mixture of bivariate Gaussian distributions:

```
MU = [1 2;-3 -5];
SIGMA = cat(3,[2 0;0 .5],[1 0;0 1]);
p = ones(1,2)/2;
obj = gmdistribution(MU,SIGMA,p);
```

```
ezcontour(@(x,y)pdf(obj,[x y]),[-10 10],[-10 10])
hold on
```

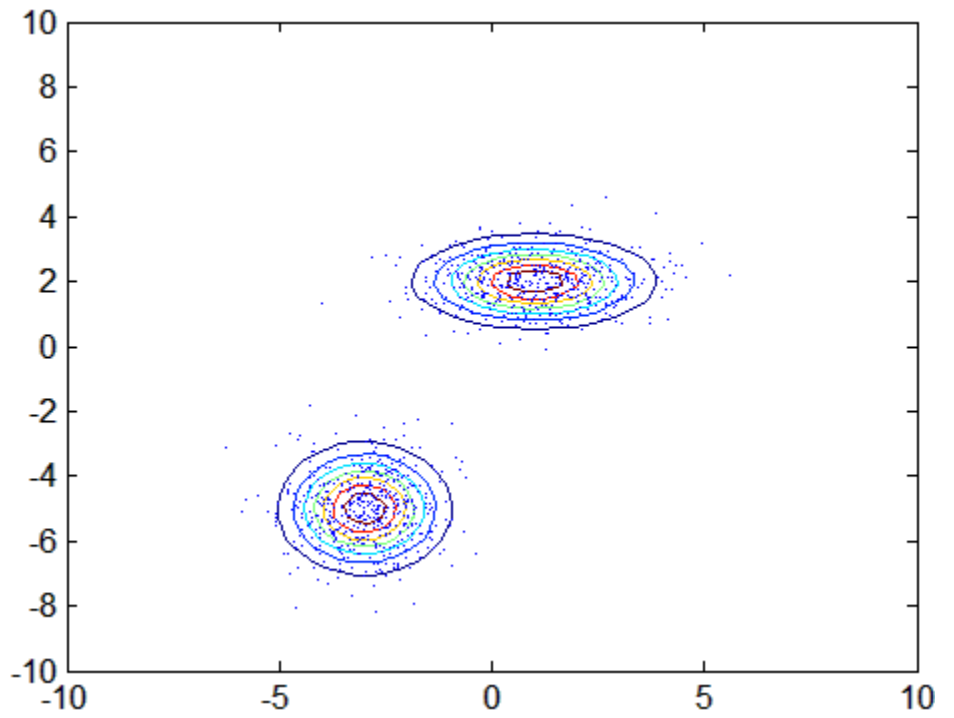
gmdistribution.random



Generate 1000 random values:

```
Y = random(obj,1000);
```

```
scatter(Y(:,1),Y(:,2),10,'.')
```



See Also

[gmdistribution](#) | [fit](#) | [mvnrnd](#)

LinearModel.random

Purpose Simulate responses for linear regression model

Syntax `ysim = random mdl, Xnew`

Description `ysim = random mdl, Xnew` simulates responses from the `mdl` linear model to the data in `Xnew`, adding random noise.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

Xnew

Points at which `mdl` predicts responses.

- If `Xnew` is a dataset array, it must contain the predictor names in `mdl`.
- If `Xnew` is a numeric matrix, it must have the same number of variables (columns) as was used to create `mdl`. Furthermore, all variables used in creating `mdl` must be numeric.

Output Arguments

ysim

Vector of predicted mean values at `Xnew`, perturbed by random noise. The noise is independent, normally distributed, with mean zero, and variance equal to the estimated error variance of the model.

Examples

Simulate Response Data

Create a model of car mileage as a function of weight, and simulate the response.

Create a quadratic model of car mileage as a function of weight from the `carsmall` data.

```
load carsmall
X = Weight;
```

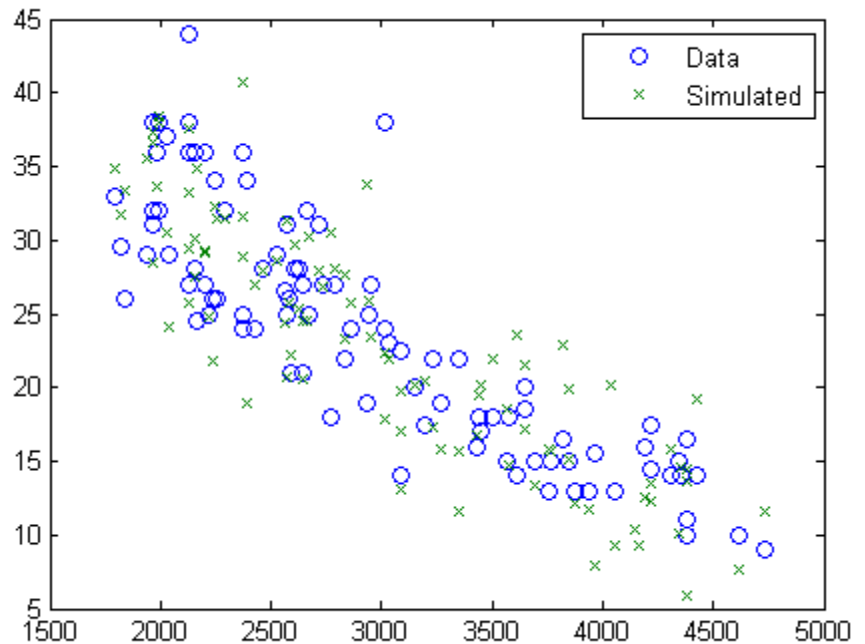
```
y = MPG;  
mdl = LinearModel.fit(X,y,'quadratic');
```

Create simulated responses to the data.

```
Xnew = X;  
ysim = random(mdl,Xnew);
```

Plot the original responses and the simulated responses to see how they differ.

```
plot(X,y,'o',X,ysim,'x')  
legend('Data','Simulated')
```



LinearModel.random

Alternatives For predictions without random noise, use `predict` or `feval`.

See Also `feval` | `LinearModel` | `predict`

Tutorials

- “random” on page 9-38

How To

- “Linear Regression” on page 9-7

Purpose

Simulate responses for nonlinear regression model

Syntax

```
ysim = random mdl,Xnew)
ysim = random mdl,Xnew, 'Weights',W)
```

Description

`ysim = random(mdl,Xnew)` simulates responses from the `mdl` nonlinear model to the data in `Xnew`, adding random noise.

`ysim = random(mdl,Xnew, 'Weights',W)` simulates responses using the observation weights, `W`.

Input Arguments**mdl**

Nonlinear regression model, constructed by `NonLinearModel.fit`.

Xnew

Points at which `mdl` predicts responses.

- If `Xnew` is a dataset array, it must contain the predictor names in `mdl`.
- If `Xnew` is a numeric matrix, it must have the same number of variables (columns) as was used to create `mdl`. Furthermore, all variables used in creating `mdl` must be numeric.

W

Vector of real, positive value weights or a function handle.

- If you specify a vector, then it must have the same number of elements as the number of observations (or rows) in `Xnew`.
- If you specify a function handle, the function must accept a vector of predicted response values as input, and returns a vector of real positive weights as output.

Given weights, `W`, `random` estimates the error variance at observation `i` by $MSE * (1/W(i))$, where `MSE` is the mean squared error.

NonLinearModel.random

Default: No weights

Output Arguments

ysim

Vector of predicted mean values at X_{new} , perturbed by random noise. The noise is independent, normally distributed, with mean zero, and variance equal to the estimated error variance of the model.

Examples

Simulate Responses

Create a nonlinear model of car mileage as a function of weight, and simulate the response.

Create an exponential model of car mileage as a function of weight from the `carsmall` data. Scale the weight by a factor of 1000 so all the variables are roughly equal in size.

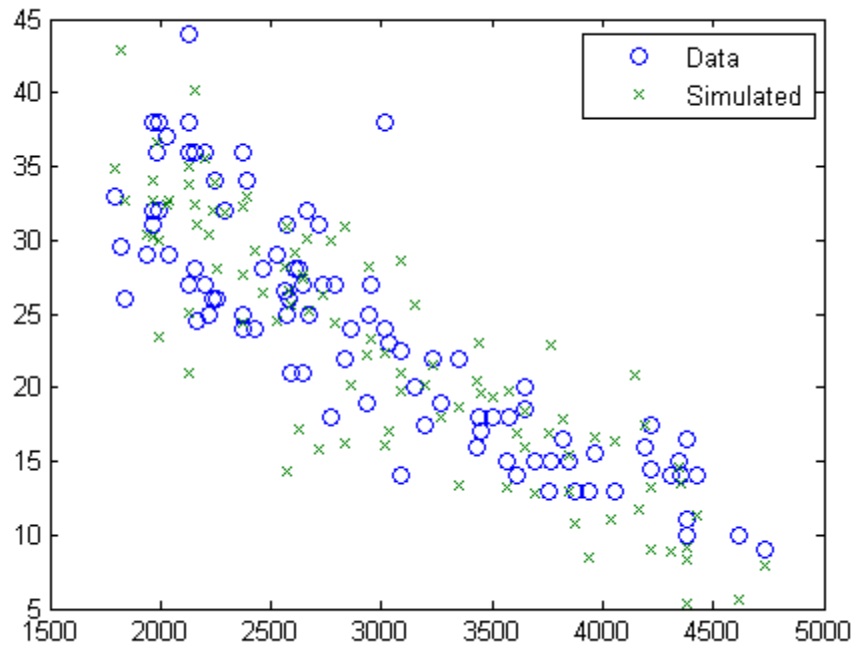
```
load carsmall
X = Weight;
y = MPG;
modelfun = 'y ~ b1 + b2*exp(-b3*x/1000)';
beta0 = [1 1 1];
mdl = NonLinearModel.fit(X,y,modelfun,beta0);
```

Create simulated responses to the data.

```
Xnew = X;
ysim = random(mdl,Xnew);
```

Plot the original responses and the simulated responses to see how they differ.

```
plot(X,y,'o',X,ysim,'x')
legend('Data','Simulated')
```



Alternatives

For predictions without added noise, use `predict`.

See Also

`feval` | `NonLinearModel` | `predict` |

Related Examples

- “Predict or Simulate Responses to New Data” on page 9-206

Concepts

- “Nonlinear Regression” on page 9-196

piecewisedistribution.random

Purpose Random numbers from piecewise distribution

Syntax

```
r = random(obj)
R = random(obj,n)
R = random(obj,m,n)
R = random(obj,[m,n])
R = random(obj,m,n,p,...)
R = random(obj,[m,n,p,...])
```

Description `r = random(obj)` generates a pseudo-random number `r` drawn from the piecewise distribution object `obj`.

`R = random(obj,n)` generates an n -by- n matrix of pseudo-random numbers `R`.

`R = random(obj,m,n)` or `R = random(obj,[m,n])` generates an m -by- n matrix of pseudo-random numbers `R`.

`R = random(obj,m,n,p,...)` or `R = random(obj,[m,n,p,...])` generates an m -by- n -by- p -by-... array of pseudo-random numbers `R`.

Examples Fit Pareto tails to a t distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);
obj = paretotails(t,0.1,0.9);
```

```
r = random(obj)
r =
    0.8285
```

See Also `paretotails` | `cdf` | `icdf`

Purpose Generate random number drawn from ProbDist object

Syntax

```
Y = random(PD)
Y = random(PD, N)
Y = random(PD, N, M, ...)
```

Description

$Y = \text{random}(PD)$ generates a random number drawn from the distribution specified by PD , a ProbDist object.

$Y = \text{random}(PD, N)$ generates an N -by- N array of random numbers drawn from the distribution specified by PD , a ProbDist object.

$Y = \text{random}(PD, N, M, \dots)$ generates an N -by- M -by- \dots array of random numbers drawn from the distribution specified by PD , a ProbDist object.

Input Arguments

PD	An object of the class ProbDistUnivParam or ProbDistUnivKernel.
N	A positive integer.
M	A positive integer.

Output Arguments

Y	A random number drawn from the distribution specified by PD .
-----	---

See Also random

randsample

Purpose Random sample

Syntax

```
y = randsample(n,k)
y = randsample(population,k)
y = randsample(n,k,replacement)
y = randsample(population,k,replacement)
y = randsample(n,k,true,w)
y = randsample(population,k,true,w)
y = randsample(s,...)
```

Description

`y = randsample(n,k)` returns a k -by-1 vector y of values sampled uniformly at random, without replacement, from the integers 1 to n .

`y = randsample(population,k)` returns a vector of k values sampled uniformly at random, without replacement, from the values in the vector `population`. The orientation of y (row or column) is the same as `population`.

`y = randsample(n,k,replacement)` or `y = randsample(population,k,replacement)` returns a sample taken with replacement if `replacement` is `true`, or without replacement if `replacement` is `false`. The default is `false`.

`y = randsample(n,k,true,w)` or `y = randsample(population,k,true,w)` returns a weighted sample taken with replacement, using a vector of positive weights w , whose length is n . The probability that the integer i is selected for an entry of y is $w(i) / \text{sum}(w)$. Usually, w is a vector of probabilities. `randsample` does not support weighted sampling without replacement.

`y = randsample(s,...)` uses the stream `s` for random number generation. `s` is a member of the `RandStream` class. Default is the MATLAB default random number stream.

Examples Draw a single value from the integers 1 through 10:

```
n = 10;
x = randsample(n,1);
```

Draw a single value from the population 1 through n, where $n > 1$:

```
y = randsample(1:n,1);
```

Note If `population` is a numeric vector containing only nonnegative integer values, and `population` can have length 1, use

```
y = population(randsample(length(population),k))
```

instead of `y = randsample(population,k)`.

Generate a random sequence of the characters A, C, G, and T, with replacement, according to the specified probabilities.

```
R = randsample('ACGT',48,true,[0.15 0.35 0.35 0.15])
```

See Also

[rand](#) | [randperm](#) | [RandStream](#)

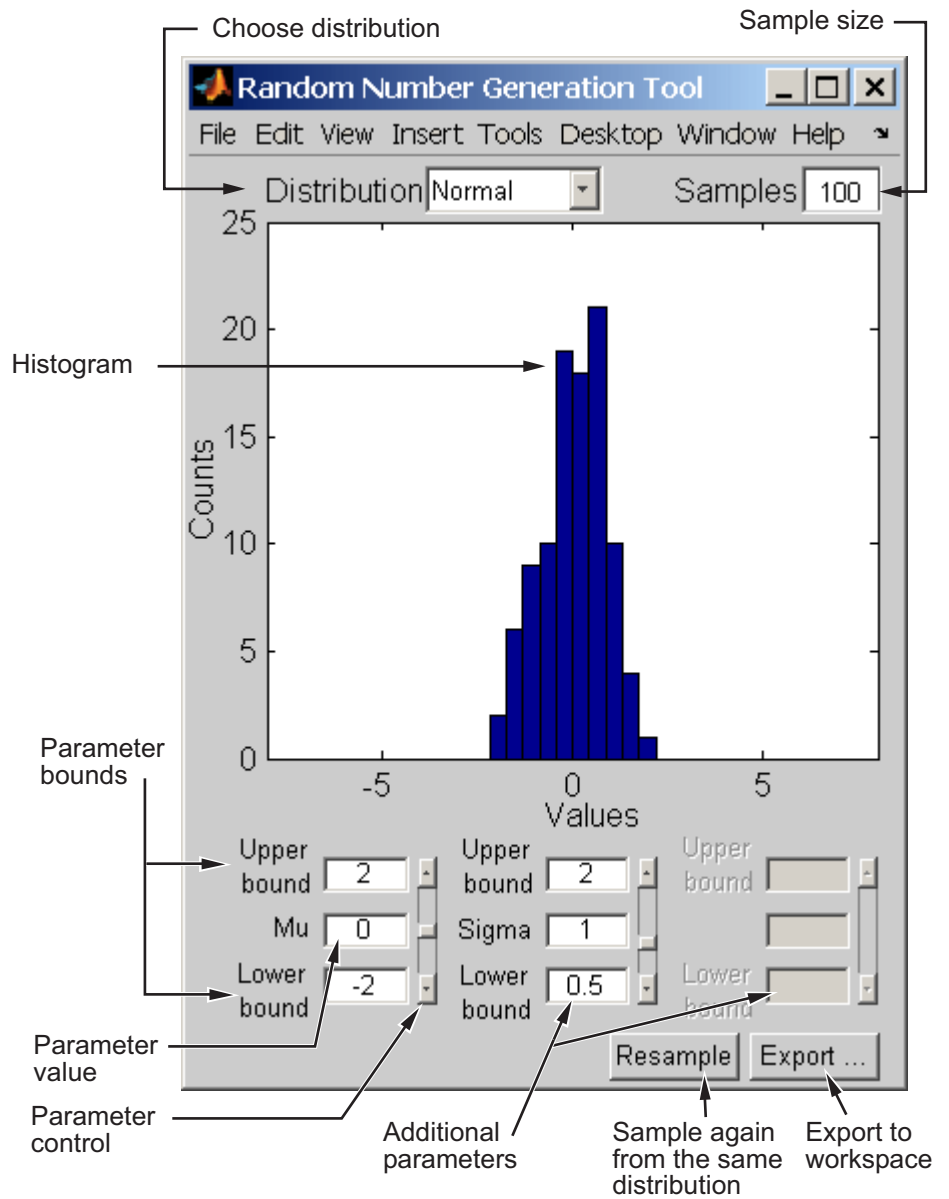
randtool

Purpose Interactive random number generation

Syntax randtool

Description randtool opens the Random Number Generation Tool.

The Random Number Generation Tool is a graphical user interface that generates random samples from specified probability distributions and displays the samples as histograms. Use the tool to explore the effects of changing parameters and sample size on the distributions.



randtool

Start by selecting a distribution, then enter the desired sample size.

You can also

- Use the controls at the bottom of the window to set parameter values for the distribution and to change their upper and lower bounds.
- Draw another sample from the same distribution, with the same size and parameters.
- Export the current sample to your workspace. A dialog box enables you to provide a name for the sample.

See Also

`disttool` | `dffitool`

Purpose

Range of values

Syntax

```
range(X)
y = range(X,dim)
```

Description

`range(X)` returns the difference between the maximum and the minimum of a sample. For vectors, `range(x)` is the range of the elements. For matrices, `range(X)` is a row vector containing the range of each column of `X`. For N-dimensional arrays, `range` operates along the first nonsingleton dimension of `X`.

`y = range(X,dim)` operates along the dimension `dim` of `X`.

`range` treats NaNs as missing values and ignores them.

The range is an easily-calculated estimate of the spread of a sample. Outliers have an undue influence on this statistic, which makes it an unreliable estimator.

Examples

The range of a large sample of standard normal random numbers is approximately six. This is the motivation for the process capability indices C_p and C_{pk} in statistical quality control applications.

```
rv = normrnd(0,1,1000,5);
near6 = range(rv)
near6 =
    6.1451    6.4986    6.2909    5.8894    7.0002
```

See Also

`std` | `iqr` | `mad`

rangesearch

Purpose Find all neighbors within specified distance

Syntax
`idx = rangesearch(X,Y,r)`
`[idx,D]= rangesearch(X,Y,r)`
`[idx,D]= rangesearch(X,Y,r,Name,Value)`

Description `idx = rangesearch(X,Y,r)` finds all the X points that are within distance r of the Y points. Rows of X and Y correspond to observations, and columns correspond to variables.

`[idx,D]= rangesearch(X,Y,r)` returns the distances between each row of Y and the rows of X that are r or less distant.

`[idx,D]= rangesearch(X,Y,r,Name,Value)` finds nearby points with additional options specified by one or more **Name,Value** pair arguments.

Tips

- For a fixed positive integer K , `knnsearch` finds K points in X that are nearest each Y point. In contrast, for a fixed positive real value r , `rangesearch` finds all the X points that are within a distance r of each Y point.

Input Arguments

X

$m \times n$ -by- n numeric matrix, where each row represents one n -dimensional point. The number of columns n must equal as the number of columns in Y.

Y

$m \times n$ -by- n numeric matrix, where each row represents one n -dimensional point. The number of columns n must equal as the number of columns in X.

r

Search radius, a scalar. `rangesearch` finds all X points (rows) that are within distance r of each Y point. The meaning of distance depends on the **Distance** name-value pair.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

BucketSize

Maximum number of data points in the leaf node of the *kd*-tree. This argument is only meaningful when *kd*-tree is used for finding nearest neighbors.

Default: 50

Cov

Positive definite matrix indicating the covariance matrix when computing the Mahalanobis distance. This argument is only valid when the `Distance` name-value pair is 'mahalanobis'.

Default: `nancov(X)`

Distance

String or function handle specifying the distance metric.

Value	Description
'euclidean'	Euclidean distance.
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between <code>X</code> and a query point is scaled, meaning divided by a scale value <code>S</code> . The default value of <code>S</code> is the standard deviation computed from <code>X</code> , <code>S=nanstd(X)</code> . To specify another value for <code>S</code> , use the <code>Scale</code> name-value pair.

Value	Description
'mahalanobis'	Mahalanobis distance, computed using a positive definite covariance matrix C . The default value of C is the sample covariance matrix of X , as computed by <code>nancov(X)</code> . To specify a different value for C , use the 'Cov' name-value pair.
'cityblock'	City block distance.
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use the 'P' name-value pair.
'chebychev'	Chebychev distance (maximum coordinate difference).
'cosine'	One minus the cosine of the included angle between observations (treated as vectors).
'correlation'	One minus the sample linear correlation between observations (treated as sequences of values).
'hamming'	Hamming distance, percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, the percentage of nonzero coordinates that differ.

Value	Description
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
@ <i>distfun</i>	Distance function handle. <i>distfun</i> has the form <pre>function D2 = DISTFUN(ZI,ZJ) ...</pre> where <ul style="list-style-type: none"> • ZI is a 1-by-N vector containing one row of X or Y. • ZJ is an M2-by-N matrix containing multiple rows of X or Y. • D2 is an M2-by-1 vector of distances, D2(k) is the distance between the observations ZI and ZJ(J,:).

For definitions, see “Distance Metrics” on page 13-9.

Default: 'euclidean'

NSMethod

Nearest neighbors search method.

rangesearch

Value	Meaning
'kdtree'	Creates and uses a <i>kd</i> -tree to find nearest neighbors. 'kdtree' is only valid when the distance metric is one of: <ul style="list-style-type: none">• 'chebyshev'• 'cityblock'• 'euclidean'• 'minkowski'
'exhaustive'	Uses the exhaustive search algorithm. The distances from all X points to each Y point are computed to find nearest neighbors.

Default: 'kdtree' when the number of columns of X is not greater than 10, X is not sparse, and the distance metric is one of the valid 'kdtree' metrics. Otherwise, the default is 'exhaustive'.

P

Positive scalar indicating the exponent of Minkowski distance. This argument is only valid when the Distance name-value pair is 'minkowski'.

Default: 2

Scale

Vector S containing nonnegative values, with length equal to the number of columns in X. Each coordinate difference between X and a query point is scaled by the corresponding element of S. This argument is only valid when the Distance name-value pair is 'seuclidean'.

Default: nanstd(X)

Output Arguments**idx**

m_y-by-1 cell array, where *m_y* is the number of rows in *Y*. *idx{I}* contains the indices of points (rows) in *X* whose distances to *Y(I, :)* are not greater than *r*. The entries in *idx{I}* are in ascending order of distance.

D

m_y-by-1 cell array, where *m_y* is the number of rows in *Y*. *D{I}* contains the distance values between *Y(I, :)* and the corresponding points in *idx{I}*.

Definitions**Distance Metrics**

For definitions, see “Distance Metrics” on page 13-9.

Examples

Find the *X* points that are within a Euclidean distance 1.5 of each *Y* point. Both *X* and *Y* are samples of 5-D normally distributed variables.

```
rng('default') % for reproducibility
X = randn(100,5);
Y = randn(10,5);
[idx, dist] = rangesearch(X,Y,1.5)
```

```
idx =
    [1x7 double]
    [1x2 double]
    [1x11 double]
    [1x2 double]
    [1x12 double]
    [1x9 double]
    [      89]
    [1x0 double]
    [1x0 double]
    [1x0 double]
```

```
dist =
```

rangesearch

```
[1x7 double]
[1x2 double]
[1x11 double]
[1x2 double]
[1x12 double]
[1x9 double]
[    1.1739]
[1x0 double]
[1x0 double]
[1x0 double]
```

In this case, the last three Y points are more than 1.5 distant from any X point. X(89, :) is 1.1739 distant from Y(7, :), and there is no other X point that is within distance 1.5 of Y(7, :). There are 12 points in X within distance 1.5 of Y(5, :).

Algorithms

For an overview of the *kd*-tree algorithm, see “*k*-Nearest Neighbor Search Using a *kd*-Tree” on page 13-14.

The exhaustive search algorithm finds the distance of each point in X to each point in Y.

Alternatives

`rangesearch` is the `ExhaustiveSearcher` method for distance search. It is equivalent to the `rangesearch` function with the `NSMethod` name-value pair set to `'exhaustive'`.

`rangesearch` is the `KDTreeSearcher` method for distance search. It is equivalent to the `rangesearch` function with the `NSMethod` name-value pair set to `'kdtree'`.

See Also

`createns` | `ExhaustiveSearcher` | `KDTreeSearcher` | `knnsearch` | `pdist2`

How To

- “*k*-Nearest Neighbor Search and Radius Search” on page 13-12

Purpose Find all neighbors within specified distance using ExhaustiveSearcher object

Syntax

```
idx = rangesearch(NS,Y,r)
[idx,D]= rangesearch(NS,Y,r)
[idx,D]= rangesearch(NS,Y,r,Name,Value)
```

Description

`idx = rangesearch(NS,Y,r)` finds all points in `NS.X` that are within distance `r` of the `Y` points. Rows of `NS.X` and `Y` correspond to observations, and columns correspond to variables.

`[idx,D]= rangesearch(NS,Y,r)` returns the distances between each row of `Y` and the rows of `NS.X` that are `r` or less distant.

`[idx,D]= rangesearch(NS,Y,r,Name,Value)` finds nearby points with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For a fixed positive integer `K`, `knnsearch` finds the `K` points in `NS.X` that are nearest each `Y` point. In contrast, for a fixed positive real value `r`, `rangesearch` finds all the points in `NS.X` that are within a distance `r` of each `Y` point.

Input Arguments

NS

ExhaustiveSearcher object, constructed using ExhaustiveSearcher or createns.

Y

m-by-*n* numeric matrix, where each row represents one *n*-dimensional point. The number of columns *n* must equal the number of columns in `NS.X`.

r

Search radius, a scalar. `rangesearch` finds all `NS.X` points (rows) that are within distance `r` of each `Y` point. The meaning of distance depends on the `Distance` name-value pair.

ExhaustiveSearcher.rangearch

Name-Value Pair Arguments

Specify optional comma-separated pairs of **Name**, **Value** arguments, where **Name** is the argument name and **Value** is the corresponding value. **Name** must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as **Name1**, **Value1**, . . . , **NameN**, **ValueN**.

Cov

Positive definite matrix indicating the covariance matrix when computing the Mahalanobis distance. This argument is only valid when the **Distance** name-value pair is 'mahalanobis'.

Default: `nancov(X)`

Distance

String or function handle specifying the distance metric.

Value	Description
'euclidean'	Euclidean distance.
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between X and a query point is scaled, meaning divided by a scale value S . The default value of S is the standard deviation computed from X , <code>S=nanstd(X)</code> . To specify another value for S , use the Scale name-value pair.
'mahalanobis'	Mahalanobis distance, computed using a positive definite covariance matrix C . The default value of C is the sample covariance matrix of X , as computed by <code>nancov(X)</code> . To specify a different value for C , use the 'Cov' name-value pair.
'cityblock'	City block distance.

Value	Description
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use the 'P' name-value pair.
'chebychev'	Chebychev distance (maximum coordinate difference).
'cosine'	One minus the cosine of the included angle between observations (treated as vectors).
'correlation'	One minus the sample linear correlation between observations (treated as sequences of values).
'hamming'	Hamming distance, percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, the percentage of nonzero coordinates that differ.
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
@ <i>distfun</i>	Distance function handle. <i>distfun</i> has the form function D2 = DISTFUN(ZI,ZJ) ... where <ul style="list-style-type: none">• ZI is a 1-by-N vector containing one row of X or Y.• ZJ is an M2-by-N matrix containing multiple rows of X or Y.

ExhaustiveSearcher.rangearch

Value	Description
	<ul style="list-style-type: none">D2 is an M2-by-1 vector of distances, D2(k) is the distance between the observations ZI and ZJ(J, :).

For definitions, see “Distance Metrics” on page 13-9.

Default: 'euclidean'

P

Positive scalar indicating the exponent of Minkowski distance. This argument is only valid when the Distance name-value pair is 'minkowski'.

Default: 2

Scale

Vector S containing nonnegative values, with length equal to the number of columns in X. Each coordinate difference between X and a query point is scaled by the corresponding element of S. This argument is only valid when the Distance name-value pair is 'seuclidean'.

Default: nanstd(X)

Output Arguments

idx

*m*y-by-1 cell array, where *m*y is the number of rows in Y. idx{I} contains the indices of points (rows) in NS.X whose distances to Y(I, :) are not greater than r. The entries in idx{I} are in ascending order of distance.

D

m_y -by-1 cell array, where m_y is the number of rows in Y .
 $D\{I\}$ contains the distance values between $Y(I,:)$ and the corresponding points in $idx\{I\}$.

Definitions

Distance Metrics

For definitions, see “Distance Metrics” on page 13-9.

Examples

Create X and Y as samples of 5-D normally distributed variables. Create an ExhaustiveSearcher object NS from X . Find the points in $NS.X$ that are within a Euclidean distance 1.5 of each point in Y .

```
rng('default') % for reproducibility
X = randn(100,5);
Y = randn(10,5);
NS = ExhaustiveSearcher(X);
[idx, dist] = rangesearch(NS,Y,1.5)
```

```
idx =
    [1x7 double]
    [1x2 double]
    [1x11 double]
    [1x2 double]
    [1x12 double]
    [1x9 double]
    [          89]
    [1x0 double]
    [1x0 double]
    [1x0 double]
```

```
dist =
    [1x7 double]
    [1x2 double]
    [1x11 double]
    [1x2 double]
    [1x12 double]
    [1x9 double]
```

ExhaustiveSearcher.rangesearch

```
[      1.1739]
[1x0 double]
[1x0 double]
[1x0 double]
```

In this case, the last three points in Y are more than 1.5 distant from any point in $NS.X$. $NS.X(89, :)$ is 1.1739 distant from $Y(7, :)$, and there is no other point in $NS.X$ that is within distance 1.5 of $Y(7, :)$. There are 12 points in $NS.X$ within distance 1.5 of $Y(5, :)$.

Algorithms

The exhaustive search algorithm finds the distance of each point in X to each point in Y .

Alternatives

`rangesearch` is the `ExhaustiveSearcher` method for distance search. It is equivalent to the `rangesearch` function with the `NSMethod` name-value pair set to `'exhaustive'`.

`rangesearch` is the `KDTreeSearcher` method for distance search. It is equivalent to the `rangesearch` function with the `NSMethod` name-value pair set to `'kdtree'`.

See Also

`createns` | `ExhaustiveSearcher` | `knnsearch` | `pdist2` | `rangesearch`

Purpose

Find all neighbors within specified distance using KDTreeSearcher object

Syntax

```
idx = rangesearch(NS,Y,r)
[idx,D]= rangesearch(NS,Y,r)
[idx,D]= rangesearch(NS,Y,r,Name,Value)
```

Description

`idx = rangesearch(NS,Y,r)` finds all points in `NS.X` that are within distance `r` of the `Y` points. Rows of `NS.X` and `Y` correspond to observations, and columns correspond to variables.

`[idx,D]= rangesearch(NS,Y,r)` returns the distances between each row of `Y` and the rows of `NS.X` that are `r` or less distant.

`[idx,D]= rangesearch(NS,Y,r,Name,Value)` finds nearby points with additional options specified by one or more `Name,Value` pair arguments.

Tips

- For a fixed positive integer `K`, `knnsearch` finds the `K` points in `NS.X` that are nearest each `Y` point. In contrast, for a fixed positive real value `r`, `rangesearch` finds all the points in `NS.X` that are within a distance `r` of each `Y` point.

Input Arguments

NS

KDTreeSearcher object, constructed using KDTreeSearcher or createns.

Y

m-by-*n* numeric matrix, where each row represents one *n*-dimensional point. The number of columns *n* must equal the number of columns in `NS.X`.

r

Search radius, a scalar. `rangesearch` finds all `NS.X` points (rows) that are within distance `r` of each `Y` point. The meaning of distance depends on the `Distance` name-value pair.

KDTreeSearcher.rangearch

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Distance

String or function handle specifying the distance metric.

Value	Description
'euclidean'	Euclidean distance.
'cityblock'	City block distance.
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use the 'P' name-value pair.
'chebychev'	Chebychev distance (maximum coordinate difference).

For definitions, see “Distance Metrics” on page 13-9.

Default: `NS.Distance`

P

Positive scalar indicating the exponent of Minkowski distance. This argument is only valid when the `Distance` name-value pair is 'minkowski'.

Default: 2

Output Arguments

idx

*m*y-by-1 cell array, where *m*y is the number of rows in *Y*. `idx{I}` contains the indices of points (rows) in `NS.X` whose distances

to $Y(I, :)$ are not greater than r . The entries in $idx\{I\}$ are in ascending order of distance.

D

m_y -by-1 cell array, where m_y is the number of rows in Y .
 $D\{I\}$ contains the distance values between $Y(I, :)$ and the corresponding points in $idx\{I\}$.

Definitions

Distance Metrics

For definitions, see “Distance Metrics” on page 13-9.

Examples

Create X and Y as samples of 5-D normally distributed variables. Create a `KDTreeSearcher` object NS from X . Find the points in $NS.X$ that are within a Euclidean distance 1.5 of each point in Y .

```
rng('default') % for reproducibility
X = randn(100,5);
Y = randn(10,5);
NS = KDTreeSearcher(X);
[idx, dist] = rangesearch(NS,Y,1.5)
```

```
idx =
    [1x7 double]
    [1x2 double]
    [1x11 double]
    [1x2 double]
    [1x12 double]
    [1x9 double]
    [      89]
    [1x0 double]
    [1x0 double]
    [1x0 double]
```

```
dist =
    [1x7 double]
    [1x2 double]
```

KDTreeSearcher.rangesearch

```
[1x11 double]
[1x2  double]
[1x12 double]
[1x9  double]
[      1.1739]
[1x0  double]
[1x0  double]
[1x0  double]
```

In this case, the last three points in *Y* are more than 1.5 distant from any point in *NS.X*. *NS.X*(89,:) is 1.1739 distant from *Y*(7,:), and there is no other point in *NS.X* that is within distance 1.5 of *Y*(7,:). There are 12 points in *NS.X* within distance 1.5 of *Y*(5,:).

Algorithms

For an overview of the *kd*-tree algorithm, see “*k*-Nearest Neighbor Search Using a *kd*-Tree” on page 13-14.

Alternatives

`rangesearch` is the `KDTreeSearcher` method for distance search. It is equivalent to the `rangesearch` function with the `NSMethod` name-value pair set to `'kdtree'`.

`rangesearch` is the `ExhaustiveSearcher` method for distance search. It is equivalent to the `rangesearch` function with the `NSMethod` name-value pair set to `'exhaustive'`.

See Also

`createns` | `KDTreeSearcher` | `knnsearch` | `pdist2` | `rangesearch`

Purpose

Wilcoxon rank sum test

Syntax

```
p = ranksum(x,y)
[p,h] = ranksum(x,y)
[p,h,stats] = ranksum(x,y)
[ ___ ] = ranksum(x,y,Name,Value)
```

Description

`p = ranksum(x,y)` returns the p -value of a two-sided Wilcoxon rank sum test. `ranksum` tests the null hypothesis that data in `x` and `y` are samples from continuous distributions with equal medians, against the alternative that they are not. The test assumes that the two samples are independent. `x` and `y` can have different lengths.

This test is equivalent to a Mann-Whitney U-test.

`[p,h] = ranksum(x,y)` also returns a logical value indicating the test decision. The result `h = 1` indicates a rejection of the null hypothesis, and `h = 0` indicates a failure to reject the null hypothesis at the 5% significance level.

`[p,h,stats] = ranksum(x,y)` also returns the structure `stats` with information about the test statistic.

`[___] = ranksum(x,y,Name,Value)` returns any of the output arguments in the previous syntaxes, for a rank sum test with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments**x - Sample data**

vector

Sample data, specified as a vector.

Data Types

single | double

y - Sample data

vector

Sample data, specified as a vector. The length of *y* does not have to be the same as the length of *x*.

Data Types

single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of *Name*, *Value* arguments, where *Name* is the argument name and *Value* is the corresponding value. *Name* must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as *Name1*, *Value1*, ..., *NameN*, *ValueN*.

Example: 'alpha',0.01,'method','approximate','tail','right' specifies a right-tailed rank sum test with 1% significance level, which returns the approximate *p*-value.

alpha - Significance level

0.05 (default) | scalar value in the range 0 to 1

Significance level of the decision of a hypothesis test, specified as the comma-separated pair consisting of 'alpha' and a scalar value in the range 0 to 1. The significance level of *h* is 100 * alpha%.

Example: 'alpha', 0.01

Data Types

double | single

method - Computation method of the *p*-value

'exact' | 'approximate'

Computation method of the *p*-value, *p*, specified as the comma-separated pair consisting of 'method' and one of the following:

'exact'	Exact computation of the <i>p</i> -value, <i>p</i> .
'approximate'	Normal approximation while computing the <i>p</i> -value, <i>p</i> .

When 'method' is unspecified, the default is:

- 'exact' if $\min(n_x, n_y) < 10$ and $n_x + n_y < 20$
- 'approximate' otherwise

n_x and n_y are the sizes of the samples in x and y, respectively.

Example: 'method', 'exact'

Data Types

char

tail - Type of test

'both' (default) | 'right' | 'left'

Type of test, specified as the comma-separated pair consisting of 'tail' and one of the following:

'both'	Two-sided hypothesis test, where the alternative hypothesis states that x and y have different medians. Default test type if 'tail' is not specified.
'right'	Right-tailed hypothesis test, where the alternative hypothesis states that the median of x is greater than the median of y.
'left'	Left-tailed hypothesis test, where the alternative hypothesis states that the median of x is less than the median of y.

Example: 'tail', 'left'

Data Types

char

Output Arguments

p - p-value of the test

nonnegative scalar

p-value of the test, returned as a positive scalar from 0 to 1. p is the probability of observing a test statistic as or more extreme than

ranksum

the observed value under the null hypothesis. `ranksum` computes the two-sided p -value by doubling the most significant one-sided value.

h - Result of the hypothesis test

1 | 0

Result of the hypothesis test, returned as a logical value.

- If $h = 1$, this indicates rejection of the null hypothesis at the $100 * \alpha\%$ significance level.
- If $h = 0$, this indicates a failure to reject the null hypothesis at the $100 * \alpha\%$ significance level.

stats - Test statistics

structure

Test statistics, returned as a structure. The test statistics stored in `stats` are:

- `ranksum` : Value of the rank sum test statistic
- `zval`: Value of the z-statistic (computed when 'method' is 'approximate')

Examples

Test for Equal Median of Two Populations

Test the hypothesis of equal medians for two independent unequal-sized samples.

Generate sample data.

```
rng('default') % for reproducibility
x = unifrnd(0,1,10,1);
y = unifrnd(0.25,1.25,15,1);
```

These samples come from populations with identical distributions except for a shift of 0.25 in the location.

Test the equality of medians of x and y .


```
p = ranksum(x,y)
```

```
p =  
0.0375
```

The p -value of 0.0375 indicates that `ranksum` rejects the null hypothesis of equal medians at the default 5% significance level.

Statistics of the Test for Two Population Medians

Obtain the statistics of the test for the equality of two population medians.

Load the sample data.

```
load mileage
```

Test if the mileage per gallon is the same for the first and second type of cars.

```
[p,h,stats] = ranksum(mileage(:,1),mileage(:,2))
```

```
p =  
0.0043
```

```
h =  
1
```

```
stats =  
ranksum: 21.5000
```

Both the p -value, 0.043, and $h = 1$ indicate the rejection of the null hypothesis of equal medians at the default 5% significance level. Because the sample sizes are small (six each), `ranksum` calculates the p -value using the exact method. The structure `stats` includes only the value of the rank sum test statistic.

Increase in the Median

Test the hypothesis of an increase in the population median.

ranksum

Navigate to a folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Load the sample data.

```
load weather
```

The weather data shows the daily high temperatures taken in the same month in two consecutive years.

Perform a left-sided test to assess the increase in the median at the 1% significance level.

```
[p,h,stats] = ranksum(year1,year2,'alpha',0.01,'tail','left')
```

```
p =
```

```
    0.1271
```

```
h =
```

```
    0
```

```
stats =
```

```
    zval: -1.1403
    ranksum: 837.5000
```

Both the p -value of 0.1271 and $h = 0$ indicate that there is not enough evidence to reject the null hypothesis and conclude that there is a positive shift in the median of observed high temperatures in the same month from year 1 to year 2 at the 1% significance level. Notice that `ranksum` uses the approximate method to calculate the p -value due to the large sample sizes.

Use the exact method to calculate the p -value.

```
[p,h,stats] = ranksum(year1,year2,'alpha',0.01,'tail','left','method')
```

```
p =
```

```
    0.1273
```

```
h =
```

```
    0
```

```
stats =
```

```
    ranksum: 837.5000
```

The results of the approximate and exact methods are consistent with each other.

Definitions

Wilcoxon Rank Sum Test

The Wilcoxon rank sum test is a nonparametric test for two populations when samples are independent. If X and Y are independent samples with different sample sizes, the test statistic which `ranksum` returns is the rank sum of the first sample.

The Wilcoxon rank sum test is equivalent to the Mann-Whitney U-test. The Mann-Whitney U-test is a nonparametric test for equality of population medians of two independent samples X and Y .

The Mann-Whitney U-test statistic, U , is the number of times a y precedes an x in an ordered arrangement of the elements in the two independent samples X and Y . It is related to the Wilcoxon rank sum statistic in the following way: If X is a sample of size n_X , then

$$U = W - \frac{n_X(n_X + 1)}{2}.$$

z-Statistic

For large samples, ranksum uses a z -statistic to compute the approximate p -value of the test. If X and Y are two independent samples of size n_X and n_Y , where $n_X < n_Y$ the z -statistic is

$$z = \frac{W - E(W)}{\sqrt{V(W)}} = \frac{W - \left[\frac{n_X n_Y + n_X (n_X + 1)}{2} \right] - 0.5 * \text{sign}(W - E(W))}{\sqrt{\frac{n_X n_Y (n_X + n_Y + 1) - \text{tiescor}}{12}}},$$

with continuity correction and tie adjustment. Here tiescor is given by

$$\text{tiescor} = \frac{2 * \text{tieadj}}{(n_X + n_Y)(n_X + n_Y - 1)},$$

where ranksum uses `[ranks,tieadj] = tiedrank(x,y)` to obtain tie adjustments. The standard normal distribution gives the p -value for this z -statistic.

Algorithms

ranksum treats NaNs in x and y as missing values and ignores them.

For a two-sided test of medians with unequal sample sizes, the test statistic that ranksum returns is the rank sum of the first sample.

References

[1] Gibbons, J. D., and S. Chakraborti. *Nonparametric Statistical Inference*, 5th Ed., Boca Raton, FL: Chapman & Hall/CRC Press, Taylor & Francis Group, 2011.

[2] Hollander, M., and D. A. Wolfe. *Nonparametric Statistical Methods*. Hoboken, NJ: John Wiley & Sons, Inc., 1999.

See Also

kruskalwallis | signrank | signtest | ttest2

raylcdf

Purpose Rayleigh cumulative distribution function

Syntax `P = raylcdf(X,B)`

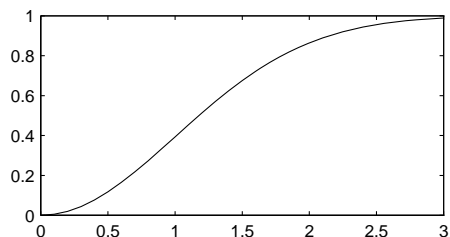
Description `P = raylcdf(X,B)` computes the Rayleigh cdf at each of the values in `X` using the corresponding scale parameter, `B`. `X` and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input for `X` or `B` is expanded to a constant array with the same dimensions as the other input.

The Rayleigh cdf is

$$y = F(x | b) = \int_0^x \frac{t}{b^2} e^{\left(\frac{-t^2}{2b^2}\right)} dt$$

Examples

```
x = 0:0.1:3;  
p = raylcdf(x,1);  
plot(x,p)
```



References

[1] Evans, M., N. Hastings, and B. Peacock. *Statistical Distributions*. Hoboken, NJ: Wiley-Interscience, 2000. pp. 134–136.

See Also

`cdf` | `raylpdf` | `raylinv` | `raylstat` | `raylfit` | `raylrnd`

How To

- “Rayleigh Distribution” on page B-104

Purpose	Rayleigh parameter estimates
Syntax	<code>raylfit(data,alpha)</code> <code>[phat,pci] = raylfit(data,alpha)</code>
Description	<code>raylfit(data,alpha)</code> returns the maximum likelihood estimates of the parameter of the Rayleigh distribution given the data in the vector <code>data</code> . <code>[phat,pci] = raylfit(data,alpha)</code> returns the maximum likelihood estimate and $100(1 - \alpha)\%$ confidence interval given the data. The default value of the optional parameter <code>alpha</code> is 0.05, corresponding to 95% confidence intervals.
See Also	<code>mle</code> <code>raylpdf</code> <code>raylcdf</code> <code>raylinv</code> <code>raylstat</code> <code>raylrnd</code>
How To	<ul style="list-style-type: none">• “Rayleigh Distribution” on page B-104

raylinv

Purpose Rayleigh inverse cumulative distribution function

Syntax `X = raylinv(P,B)`

Description `X = raylinv(P,B)` returns the inverse of the Rayleigh cumulative distribution function using the corresponding scale parameter, **B** at the corresponding probabilities in **P**. **P** and **B** can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input for **P** or **B** is expanded to a constant array with the same dimensions as the other input.

Examples

```
x = raylinv(0.9,1)
x =
    2.1460
```

See Also `raylcdf` | `raylpdf` | `raylrnd` | `raylstat`

How To

- `icdf`
- “Rayleigh Distribution” on page B-104

Purpose Rayleigh probability density function

Syntax `Y = raylpdf(X,B)`

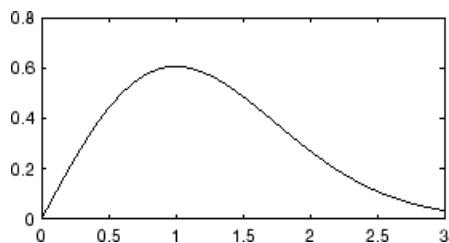
Description `Y = raylpdf(X,B)` computes the Rayleigh pdf at each of the values in `X` using the corresponding scale parameter, `B`. `X` and `B` can be vectors, matrices, or multidimensional arrays that all have the same size, which is also the size of `Y`. A scalar input for `X` or `B` is expanded to a constant array with the same dimensions as the other input.

The Rayleigh pdf is

$$y = f(x | b) = \frac{x}{b^2} e^{\left(\frac{-x^2}{2b^2}\right)}$$

Examples

```
x = 0:0.1:3;  
p = raylpdf(x,1);  
plot(x,p)
```



See Also `pdf` | `raylcdf` | `raylinv` | `raylstat` | `raylfit` | `raylrnd`

How To • “Rayleigh Distribution” on page B-104

raylrnd

Purpose Rayleigh random numbers

Syntax
`R = raylrnd(B)`
`R = raylrnd(B,v)`
`R = raylrnd(B,m,n)`

Description `R = raylrnd(B)` returns a matrix of random numbers chosen from the Rayleigh distribution with scale parameter, `B`. `B` can be a vector, a matrix, or a multidimensional array. The size of `R` is the size of `B`.

`R = raylrnd(B,v)` returns a matrix of random numbers chosen from the Rayleigh distribution with parameter `B`, where `v` is a row vector. If `v` is a 1-by-2 vector, `R` is a matrix with `v(1)` rows and `v(2)` columns. If `v` is 1-by-`n`, `R` is an `n`-dimensional array.

`R = raylrnd(B,m,n)` returns a matrix of random numbers chosen from the Rayleigh distribution with parameter `B`, where scalars `m` and `n` are the row and column dimensions of `R`.

Examples

```
r = raylrnd(1:5)
r =
    1.7986    0.8795    3.3473    8.9159    3.5182
```

See Also `random` | `raylpdf` | `raylcdf` | `raylinv` | `raylstat` | `raylfit`

How To

- “Rayleigh Distribution” on page B-104

Purpose Rayleigh mean and variance

Syntax `[M,V] = raylstat(B)`

Description `[M,V] = raylstat(B)` returns the mean of and variance for the Rayleigh distribution with scale parameter B.

The mean of the Rayleigh distribution with parameter b is $b\sqrt{\pi/2}$ and the variance is

$$\frac{4-\pi}{2}b^2$$

Examples

```
[mn,v] = raylstat(1)
mn =
    1.2533
v =
    0.4292
```

See Also `raylpdf` | `raylcdf` | `raylinv` | `raylfit` | `raylrnd`

How To

- “Rayleigh Distribution” on page B-104

rcoplot

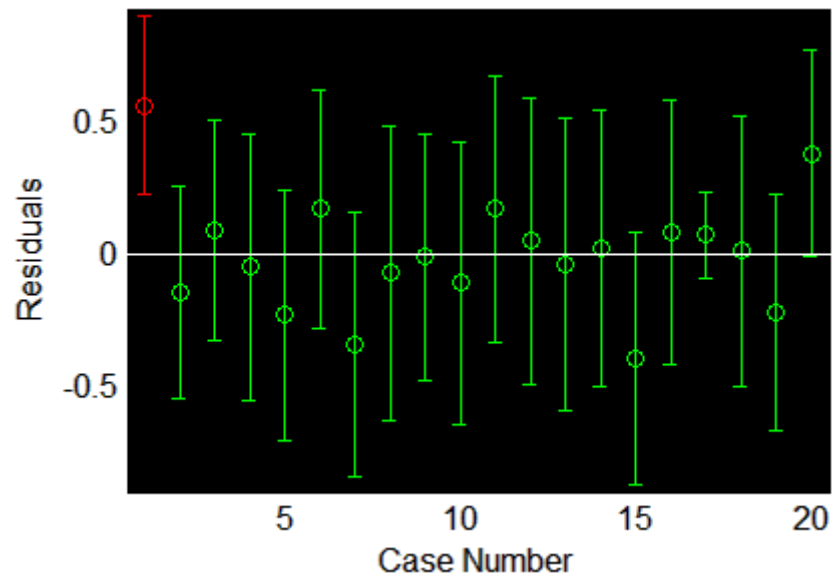
Purpose Residual case order plot

Syntax `rcoplot(r,rint)`

Description `rcoplot(r,rint)` displays an errorbar plot of the confidence intervals on the residuals from a regression. The residuals appear in the plot in case order. Inputs `r` and `rint` are outputs from the `regress` function.

Examples The following plots residuals and prediction intervals from a regression of a linearly additive model to the data in `moore.mat`:

```
load moore
X = [ones(size(moore,1),1) moore(:,1:5)];
y = moore(:,6);
alpha = 0.05;
[betahat,Ibeta,res,Ires,stats] = regress(y,X,alpha);
rcoplot(res,Ires)
```



The interval around the first residual, shown in red, does not contain zero. This indicates that the residual is larger than expected in 95% of new observations, and suggests the data point is an outlier.

See Also

`regress`

refcurve

Purpose Add reference curve to plot

Syntax `refcurve(p)`
`refcurve`
`hcurve = refcurve(...)`

Description `refcurve(p)` adds a polynomial reference curve with coefficients `p` to the current axes. If `p` is a vector with `n+1` elements, the curve is:

$$y = p(1)*x^n + p(2)*x^{(n-1)} + \dots + p(n)*x + p(n+1)$$

`refcurve` with no input arguments adds a line along the x axis.

`hcurve = refcurve(...)` returns the handle `hcurve` to the curve.

Examples

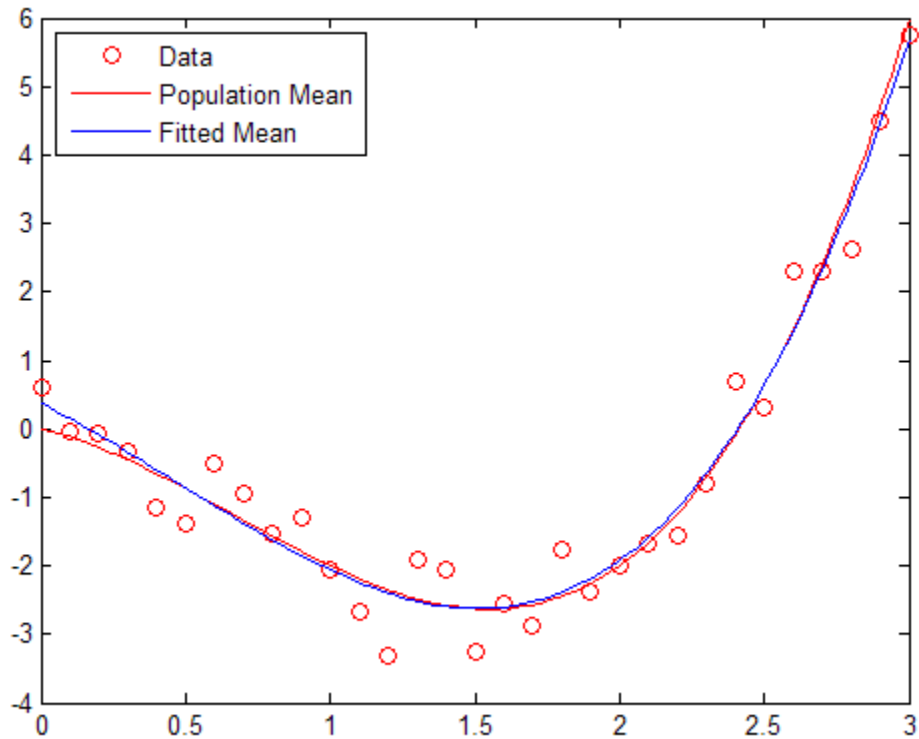
Example 1

Plot data from a population with a polynomial trend and use `refcurve` to add both the population and fitted mean functions:

```
p = [1 -2 -1 0];
t = 0:0.1:3;
y = polyval(p,t) + 0.5*randn(size(t));

plot(t,y,'ro')
h = refcurve(p);
set(h,'Color','r')

q = polyfit(t,y,3);
refcurve(q)
legend('Data','Population Mean','Fitted Mean',...
      'Location','NW')
```



Example 2

Plot trajectories of a batted baseball, with and without air resistance.

Relevant physical constants are:

$M = 0.145;$	% Mass (kg)
$R = 0.0366;$	% Radius (m)
$A = \pi \cdot R^2;$	% Area (m^2)
$\rho = 1.2;$	% Density of air (kg/m^3)
$C = 0.5;$	% Drag coefficient

refcurve

```
D = rho*C*A/2;
% Drag proportional to the square of the speed
g = 9.8;          % Acceleration due to gravity (m/s^2)
```

First, simulate the trajectory with drag proportional to the square of the speed, assuming constant acceleration in each time interval:

```
dt = 1e-2;      % Simulation time interval (s)
r0 = [0 1];     % Initial position (m)
s0 = 50;        % Initial speed (m/s)
alpha0 = 35;    % Initial angle (deg)
v0=s0*[cosd(alpha0) sind(alpha0)]; % Initial velocity (m/s)
```

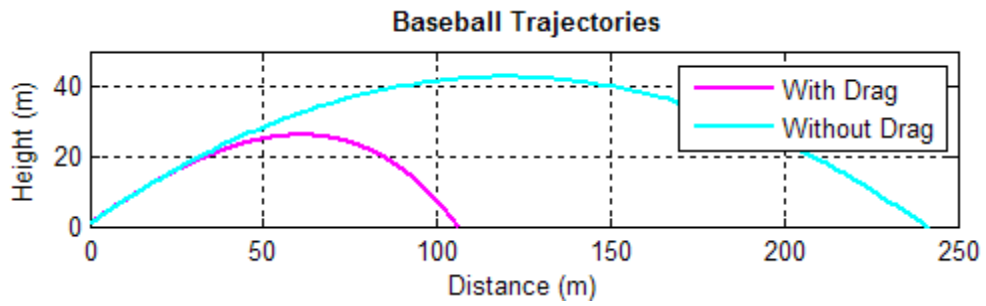
```
r = r0;
v = v0;
trajectory = r0;
while r(2) > 0
    a = [0 -g]-(D/M)*norm(v)*v;
    v = v + a*dt;
    r = r + v*dt + (1/2)*a*(dt^2);
    trajectory = [trajectory;r];
end
```

Second, use refcurve to add the drag-free parabolic trajectory (found analytically) to a plot of trajectory:

```
plot(trajectory(:,1),trajectory(:,2),'m','LineWidth',2)
xlim([0,250])
h = refcurve([-g/(2*v0(1)^2),...
    (g*r0(1)/v0(1)^2)+(v0(2)/v0(1)),...
    (-g*r0(1)^2/(2*v0(1)^2)-(v0(2)*r0(1)/v0(1))+r0(2)]);
set(h,'Color','c','LineWidth',2)
axis equal
ylim([0,50])
grid on
xlabel('Distance (m)')
ylabel('Height (m)')
title('\bf Baseball Trajectories')
```



```
legend('With Drag', 'Without Drag')
```

**See Also**

[refline](#) | [lsline](#) | [gline](#) | [polyfit](#)

refline

Purpose Add reference line to plot

Syntax `refline(m,b)`
`refline(coeffs)`
`refline`
`hline = refline(...)`

Description `refline(m,b)` adds a reference line with slope `m` and intercept `b` to the current axes.
`refline(coeffs)`, where `coeffs` is a two-element coefficient vector, adds the line

$$y = \text{coeffs}(1)*x + \text{coeffs}(2)$$

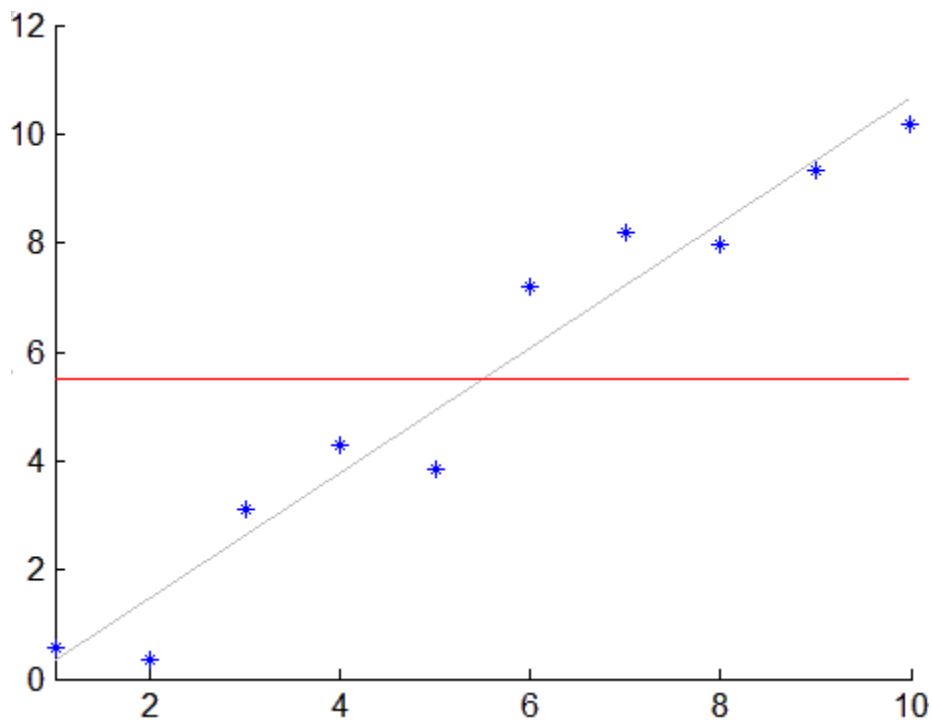
to the figure.

`refline` with no input arguments is equivalent to `lsline`.

`hline = refline(...)` returns the handle `hline` to the line.

Examples Add a reference line at the mean of a data scatter and its least-squares line:

```
x = 1:10;  
  
y = x + randn(1,10);  
scatter(x,y,25,'b','*')  
  
lsline  
  
mu = mean(y);  
hline = refline([0 mu]);  
set(hline,'Color','r')
```



See Also

refcurve | lslines | gline

regress

Purpose Multiple linear regression

Syntax

```
b = regress(y,X)
[b,bint] = regress(y,X)
[b,bint,r] = regress(y,X)
[b,bint,r,rint] = regress(y,X)
[b,bint,r,rint,stats] = regress(y,X)
[...] = regress(y,X,alpha)
```

Description `b = regress(y,X)` returns a p -by-1 vector `b` of coefficient estimates for a multilinear regression of the responses in `y` on the predictors in `X`. `X` is an n -by- p matrix of p predictors at each of n observations. `y` is an n -by-1 vector of observed responses.

`regress` treats NaNs in `X` or `y` as missing values, and ignores them.

If the columns of `X` are linearly dependent, `regress` obtains a basic solution by setting the maximum number of elements of `b` to zero.

`[b,bint] = regress(y,X)` returns a p -by-2 matrix `bint` of 95% confidence intervals for the coefficient estimates. The first column of `bint` contains lower confidence bounds for each of the p coefficient estimates; the second column contains upper confidence bounds.

If the columns of `X` are linearly dependent, `regress` returns zeros in elements of `bint` corresponding to the zero elements of `b`.

`[b,bint,r] = regress(y,X)` returns an n -by-1 vector `r` of residuals.

`[b,bint,r,rint] = regress(y,X)` returns an n -by-2 matrix `rint` of intervals that can be used to diagnose outliers. If the interval `rint(i,:)` for observation `i` does not contain zero, the corresponding residual is larger than expected in 95% of new observations, suggesting an outlier.

In a linear model, observed values of `y` are random variables, and so are their residuals. Residuals have normal distributions with zero mean but with different variances at different values of the predictors. To put residuals on a comparable scale, they are “Studentized,” that is, they are divided by an estimate of their standard deviation that is independent of their value. Studentized residuals have t distributions with known

degrees of freedom. The intervals returned in `rint` are shifts of the 95% confidence intervals of these t distributions, centered at the residuals.

`[b,bint,r,rint,stats] = regress(y,X)` returns a 1-by-4 vector `stats` that contains, in order, the R^2 statistic, the F statistic and its p value, and an estimate of the error variance.

Note When computing statistics, `X` should include a column of 1s so that the model contains a constant term. The F statistic and its p value are computed under this assumption, and they are not correct for models without a constant.

The F statistic is the test statistic of the F-test on the regression model, for a significant linear regression relationship between the response variable and the predictor variables.

The R^2 statistic can be negative for models without a constant, indicating that the model is not appropriate for the data.

`[...] = regress(y,X,alpha)` uses a $100*(1-\text{alpha})\%$ confidence level to compute `bint` and `rint`.

Examples

Load data on cars; identify weight and horsepower as predictors, mileage as the response:

```
load carsmall
x1 = Weight;
x2 = Horsepower; % Contains NaN data
y = MPG;
```

Compute regression coefficients for a linear model with an interaction term:

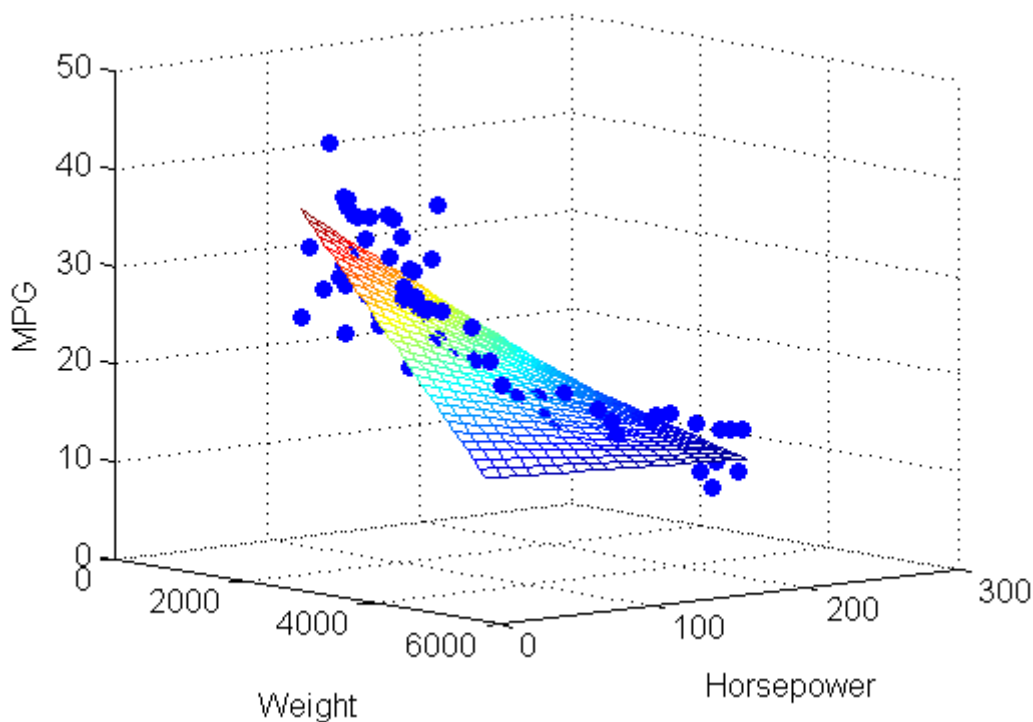
```
X = [ones(size(x1)) x1 x2 x1.*x2];
b = regress(y,X) % Removes NaN data
b =
```

regress

```
60.7104
-0.0102
-0.1882
0.0000
```

Plot the data and the model:

```
scatter3(x1,x2,y,'filled')
hold on
x1fit = min(x1):100:max(x1);
x2fit = min(x2):10:max(x2);
[X1FIT,X2FIT] = meshgrid(x1fit,x2fit);
YFIT = b(1) + b(2)*X1FIT + b(3)*X2FIT + b(4)*X1FIT.*X2FIT;
mesh(X1FIT,X2FIT,YFIT)
xlabel('Weight')
ylabel('Horsepower')
zlabel('MPG')
view(50,10)
```



References

[1] Chatterjee, S., and A. S. Hadi. “Influential Observations, High Leverage Points, and Outliers in Linear Regression.” *Statistical Science*. Vol. 1, 1986, pp. 379–416.

See Also

[LinearModel](#) | [LinearModel.fit](#) | [LinearModel.stepwise](#) | [mvregress](#) | [rcoplot](#)

Related Examples

- “Interpret Linear Regression Results” on page 9-60
- “Linear Regression Workflow” on page 9-40

Concepts

- “Linear Regression Output and Diagnostic Statistics” on page 9-68

RegressionBaggedEnsemble

Superclasses RegressionEnsemble

Purpose Regression ensemble grown by resampling

Description RegressionBaggedEnsemble combines a set of trained weak learner models and data on which these learners were trained. It can predict ensemble response for new data by aggregating predictions from its weak learners.

Construction `ens = fitensemble(X,Y,'bag',nlearn,learners,'type','regression')` creates a bagged regression ensemble. For more information on the syntax, see the `fitensemble` function reference page.

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.

CombineWeights

A string describing how the ensemble combines learner predictions.

FitInfo

A numeric array of fit information. The `FitInfoDescription` property describes the content of this array.

FitInfoDescription

String describing the meaning of the `FitInfo` array.

FResample

A numeric scalar between 0 and 1. `FResample` is the fraction of training data `fitensemble` resampled at random for every weak learner when constructing the ensemble.

LearnerNames

Cell array of strings with names of the weak learners in the ensemble. The name of each learner appears just once. For example, if you have an ensemble of 100 trees, `LearnerNames` is `{'Tree'}`.

Method

A string with the name of the algorithm `fitensemble` used for training the ensemble.

ModelParams

Parameters used in training `ens`.

NObservations

Numeric scalar containing the number of observations in the training data.

NTrained

Number of trained learners in the ensemble, a positive scalar.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

ReasonForTermination

A string describing the reason `fitensemble` stopped adding weak learners to the ensemble.

Regularization

A structure containing the result of the `regularize` method. Use `Regularization` with `shrink` to lower resubstitution error and shrink the ensemble.

Replace

Boolean flag indicating if training data for weak learners in this ensemble were sampled with replacement. `Replace` is true for sampling with replacement, false otherwise.

RegressionBaggedEnsemble

ResponseName

A string with the name of the response variable Y .

ResponseTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$.

Add or change a ResponseTransform function by dot addressing:

```
ens.ResponseTransform = @function
```

Trained

The trained learners, a cell array of compact regression models.

TrainedWeights

A numeric vector of weights the ensemble assigns to its learners. The ensemble computes predicted response by aggregating weighted predictions from its learners.

UseObsForLearner

A logical matrix of size N -by- N_{Trained} , where N is the number of rows (observations) in the training data X , and N_{Trained} is the number of trained weak learners. `UseObsForLearner(I,J)` is true if observation I was used for training learner J , and is false otherwise.

W

The scaled `weights`, a vector with length n , the number of rows in X . The sum of the elements of W is 1.

X

The matrix of predictor values that trained the ensemble. Each column of X represents one variable, and each row represents one observation.

Y

The numeric column vector with the same number of rows as X that trained the ensemble. Each entry in Y is the response to the data in the corresponding row of X.

Methods

oobLoss	Out-of-bag regression error
oobPredict	Predict out-of-bag response of ensemble

Inherited Methods

compact	Create compact regression ensemble
crossval	Cross validate ensemble
cvshrink	Cross validate shrinking (pruning) ensemble
regularize	Find weights to minimize resubstitution error plus penalty term
resubLoss	Regression error by resubstitution
resubPredict	Predict response of ensemble by resubstitution
resume	Resume training ensemble
shrink	Prune ensemble
loss	Regression error
predict	Predict response of ensemble
predictorImportance	Estimates of predictor importance
removeLearners	Remove members of compact regression ensemble

RegressionBaggedEnsemble

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Create a bagged regression ensemble to predict the mileage of cars in the `carsmall` data set based on their engine displacement, horsepower, and weight:

```
load carsmall
X = [Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'bag',100,'Tree',...
    'type','regression')

ens =

classreg.learning.regr.RegressionBaggedEnsemble:
    PredictorNames: {'x1' 'x2' 'x3'}
    CategoricalPredictors: []
    ResponseName: 'Y'
    ResponseTransform: 'none'
    NObservations: 94
    NTrained: 100
    Method: 'Bag'
    LearnerNames: {'Tree'}
    ReasonForTermination: [1x77 char]
    FitInfo: []
    FitInfoDescription: 'None'
    Regularization: []
    FResample: 1
    Replace: 1
    UseObsForLearner: [94x100 logical]
```

Predict the mileage of a car whose characteristics are the average of those of the first 10 cars:

```
car10 = mean(X(1:10,:));
predict(ens,car10)
```

```
ans =  
    14.6569
```

See Also

`RegressionEnsemble` | `fitensemble`

RegressionEnsemble

Superclasses CompactRegressionEnsemble

Purpose Ensemble regression

Description RegressionEnsemble combines a set of trained weak learner models and data on which these learners were trained. It can predict ensemble response for new data by aggregating predictions from its weak learners.

Construction `ens = fitensemble(X,Y,method,nlearn,learners)` returns an ensemble model that can predict responses to data. The ensemble consists of models listed in `learners`. For more information on the syntax, see the `fitensemble` function reference page.

`ens = fitensemble(X,Y,method,nlearn,learners,Name,Value)` returns an ensemble model with additional options specified by one or more `Name,Value` pair arguments. For more information on the syntax, see the `fitensemble` function reference page.

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.

CombineWeights

A string describing how the ensemble combines learner predictions.

FitInfo

A numeric array of fit information. The `FitInfoDescription` property describes the content of this array.

FitInfoDescription

String describing the meaning of the `FitInfo` array.

LearnerNames

Cell array of strings with names of the weak learners in the ensemble. The name of each learner appears just once. For example, if you have an ensemble of 100 trees, `LearnerNames` is `{'Tree'}`.

Method

A string with the name of the algorithm `fitensemble` used for training the ensemble.

ModelParams

Parameters used in training `ens`.

NObservations

Numeric scalar containing the number of observations in the training data.

NTrained

Number of trained learners in the ensemble, a positive scalar.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

ReasonForTermination

A string describing the reason `fitensemble` stopped adding weak learners to the ensemble.

Regularization

A structure containing the result of the `regularize` method. Use `Regularization` with `shrink` to lower resubstitution error and shrink the ensemble.

ResponseName

A string with the name of the response variable `Y`.

ResponseTransform

RegressionEnsemble

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$.

Add or change a ResponseTransform function by dot addressing:

```
ens.ResponseTransform = @function
```

Trained

The trained learners, a cell array of compact regression models.

TrainedWeights

A numeric vector of weights the ensemble assigns to its learners. The ensemble computes predicted response by aggregating weighted predictions from its learners.

W

The scaled weights, a vector with length n , the number of rows in X . The sum of the elements of W is 1.

X

The matrix of predictor values that trained the ensemble. Each column of X represents one variable, and each row represents one observation.

Y

The numeric column vector with the same number of rows as X that trained the ensemble. Each entry in Y is the response to the data in the corresponding row of X .

Methods

compact	Create compact regression ensemble
crossval	Cross validate ensemble
cvshrink	Cross validate shrinking (pruning) ensemble

regularize	Find weights to minimize resubstitution error plus penalty term
resubLoss	Regression error by resubstitution
resubPredict	Predict response of ensemble by resubstitution
resume	Resume training ensemble
shrink	Prune ensemble

Inherited Methods

loss	Regression error
predict	Predict response of ensemble
predictorImportance	Estimates of predictor importance
removeLearners	Remove members of compact regression ensemble

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Create a boosted regression ensemble to predict the mileage of cars in the `carsmall` data set based on their weights and numbers of cylinders:

```
load carsmall
learner = RegressionTree.template('MinParent',20);
ens = fitensemble([Weight, Cylinders],MPG,...
    'LSBoost',100,learner,'PredictorNames',{'W','C'},...
    'categoricalpredictors',2)

ens =
classreg.learning.regr.RegistrationEnsemble:
    PredictorNames: {'W' 'C'}
    CategoricalPredictors: 2
```

RegressionEnsemble

```
      ResponseName: 'Response'  
ResponseTransform: 'none'  
      NObservations: 94  
        NTrained: 100  
          Method: 'LSBoost'  
    LearnerNames: {'Tree'}  
ReasonForTermination: [1x77 char]  
          FitInfo: [100x1 double]  
FitInfoDescription: [2x83 char]  
  Regularization: []
```

Predict the mileage of 4,000-pound cars with 4, 6, and 8 cylinders:

```
mileage4K = predict(ens,[4000 4; 4000 6; 4000 8])
```

```
mileage4K =  
    20.0294  
    19.4206  
    15.5000
```

See Also

[ClassificationEnsemble](#) | [fitensemble](#) |
[CompactRegressionEnsemble](#)

Superclasses RegressionPartitionedModel

Purpose Cross-validated regression ensemble

Description RegressionPartitionedEnsemble is a set of regression ensembles trained on cross-validated folds. Estimate the quality of classification by cross validation using one or more “kfold” methods: `kfoldfun`, `kfoldLoss`, or `kfoldPredict`. Every “kfold” method uses models trained on in-fold observations to predict response for out-of-fold observations. For example, suppose you cross validate using five folds. In this case, every training fold contains roughly 4/5 of the data and every test fold contains roughly 1/5 of the data. The first model stored in `Trained{1}` was trained on X and Y with the first 1/5 excluded, the second model stored in `Trained{2}` was trained on X and Y with the second 1/5 excluded, and so on. When you call `kfoldPredict`, it computes predictions for the first 1/5 of the data using the first model, for the second 1/5 of data using the second model and so on. In short, response for every observation is computed by `kfoldPredict` using the model trained without this observation.

Construction `cvens = crossval(ens)` creates a cross-validated ensemble from `ens`, a regression ensemble. For syntax details, see the `crossval` method reference page.

`cvens = fitensemble(X,Y,method,nlearn,learners,name,value)` creates a cross-validated ensemble when `name` is one of 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'. For syntax details, see the `fitensemble` function reference page.

Input Arguments

ens

A regression ensemble constructed with `fitensemble`.

RegressionPartitionedEnsemble

Properties

CategoricalPredictors

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to p , where p is the number of columns of X .

CrossValidatedModel

Name of the cross-validated model, a string.

Kfold

Number of folds used in a cross-validated tree, a positive integer.

ModelParams

Object holding parameters of tree.

NObservations

Numeric scalar containing the number of observations in the training data.

NTrainedPerFold

Vector of `Kfold` elements. Each entry contains the number of trained learners in this cross-validation fold.

Partition

The partition of class `cvpartition` used in creating the cross-validated ensemble.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in X .

ResponseName

Name of the response variable Y , a string.

ResponseTransform

Function handle for transforming scores, or string representing a built-in transformation function. 'none' means no transformation; equivalently, 'none' means $@(x)x$.

Add or change a ResponseTransform function by dot addressing:

```
ens.ResponseTransform = @function
```

Trainable

Cell array of ensembles trained on cross-validation folds. Every ensemble is full, meaning it contains its training data and weights.

Trained

Cell array of compact ensembles trained on cross-validation folds.

W

The scaled weights, a vector with length n , the number of rows in X .

X

A matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

Y

A numeric column vector with the same number of rows as X . Each entry in Y is the response to the data in the corresponding row of X .

Methods

kfoldLoss	Cross-validation loss of partitioned regression ensemble
resume	Resume training ensemble

Inherited Methods

kfoldfun	Cross validate function
kfoldLoss	Cross-validation loss of partitioned regression model
kfoldPredict	Predict response for observations not used for training.

RegressionPartitionedEnsemble

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Construct a partitioned regression ensemble, and examine the cross-validation losses for the folds:

```
load carsmall
XX = [Cylinders Displacement Horsepower Weight];
YY = MPG;
rens = fitensemble(XX,YY,'LSBoost',100,'Tree');
cvrens = crossval(rens);
L = kfoldLoss(cvrens,'mode','individual')
```

```
L =
    42.4468
    12.3158
    65.9432
    39.0019
    30.5908
    16.6225
    17.3071
    46.1769
     8.0561
    12.9689
```

See Also

[ClassificationPartitionedEnsemble](#) | [RegressionPartitionedModel](#) | [RegressionEnsemble](#)

Purpose

Cross-validated regression model

Description

`RegressionPartitionedModel` is a set of regression models trained on cross-validated folds. Estimate the quality of regression by cross validation using one or more “kfold” methods: `kfoldPredict`, `kfoldLoss`, and `kfoldfun`. Every “kfold” method uses models trained on in-fold observations to predict response for out-of-fold observations. For example, suppose you cross validate using five folds. In this case, every training fold contains roughly 4/5 of the data and every test fold contains roughly 1/5 of the data. The first model stored in `Trained{1}` was trained on X and Y with the first 1/5 excluded, the second model stored in `Trained{2}` was trained on X and Y with the second 1/5 excluded, and so on. When you call `kfoldPredict`, it computes predictions for the first 1/5 of the data using the first model, for the second 1/5 of data using the second model and so on. In short, response for every observation is computed by `kfoldPredict` using the model trained without this observation.

Construction

`cvmodel = crossval(tree)` creates a cross-validated classification model from a regression tree. For syntax details, see the `crossval` method reference page.

`cvmodel = RegressionTree.fit(X,Y,name,value)` creates a cross-validated model when `name` is one of `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`. For syntax details, see the `RegressionTree.fit` function reference page.

Input Arguments

`tree`

A regression tree constructed with `RegressionTree.fit`.

Properties

`CategoricalPredictors`

List of categorical predictors. `CategoricalPredictors` is a numeric vector with indices from 1 to p , where p is the number of columns of X .

RegressionPartitionedModel

CrossValidatedModel

Name of the cross-validated model, a string.

Kfold

Number of folds used in a cross-validated tree, a positive integer.

ModelParams

Object holding parameters of `tree`.

Partition

The partition of class `cvpartition` used in the cross-validated model.

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

ResponseName

Name of the response variable `Y`, a string.

ResponseTransform

Function handle for transforming the raw response values (mean squared error). The function handle should accept a matrix of response values and return a matrix of the same size. The default string 'none' means `@(x)x`, or no transformation.

Add or change a `ResponseTransform` function by dot addressing:

```
ctree.ResponseTransform = @function
```

Trained

The trained learners, a cell array of compact regression models.

W

The scaled `weights`, a vector with length `n`, the number of rows in `X`.

X

A matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

Y

A numeric column vector with the same number of rows as X . Each entry in Y is the response to the data in the corresponding row of X .

Methods

<code>kfoldfun</code>	Cross validate function
<code>kfoldLoss</code>	Cross-validation loss of partitioned regression model
<code>kfoldPredict</code>	Predict response for observations not used for training.

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Evaluate the cross-validation error of the `carsmall` data using Horsepower and Weight as predictor variables for mileage (MPG):

```
load carsmall
X = [Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
cvtree = crossval(tree);
L = kfoldLoss(cvtree)
```

```
L =
```

```
26.4414
```

See Also

`RegressionPartitionedEnsemble` |
`ClassificationPartitionedModel`

RegressionTree

Superclasses CompactRegressionTree

Purpose Regression tree

Description A decision tree with binary splits for regression. An object of class `RegressionTree` can predict responses for new data with the `predict` method. The object contains the data used for training, so can compute resubstitution predictions.

Construction `tree = RegressionTree.fit(X,Y)` returns a regression tree based on the input variables (also known as predictors, features, or attributes) `X` and output (response) `Y`. `tree` is a binary tree where each branching node is split based on the values of a column of `X`.

`tree = RegressionTree.fit(X,Y,Name,Value)` fits a tree with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

X

A matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

`RegressionTree.fit` considers NaN values in `X` as missing values. `RegressionTree.fit` does not use observations with all missing values for `X` the fit. `RegressionTree.fit` uses observations with some missing values for `X` to find splits on variables for which these observations have valid values.

Y

A numeric column vector with the same number of rows as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

`RegressionTree.fit` considers NaN values in `Y` to be missing values. `RegressionTree.fit` does not use observations with missing values for `Y` in the fit.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

CategoricalPredictors

List of categorical predictors. Pass `CategoricalPredictors` as one of:

- A numeric vector with indices from 1 to `p`, where `p` is the number of columns of `X`.
- A logical vector of length `p`, where a true entry means that the corresponding column of `X` is a categorical variable.
- `'all'`, meaning all predictors are categorical.
- A cell array of strings, where each element in the array is the name of a predictor variable. The names must match entries in the `PredictorNames` property.
- A character matrix, where each row of the matrix is a name of a predictor variable. Pad the names with extra blanks so each row of the character matrix has the same length.

Default: `[]`

crossval

If `'on'`, grows a cross-validated decision tree with 10 folds. You can use `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'` parameters to override this cross-validation setting. You can only use one of these four parameters (`'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`) at a time when creating a cross-validated tree.

RegressionTree

Alternatively, cross-validate `tree` later using the `crossval` method.

Default: 'off'

cvpartition

A partition created with `cvpartition` to use in cross-validated tree. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout' and 'cvpartition'.

holdout

Holdout validation tests the specified fraction of the data, and uses the rest of the data for training. Specify a numeric scalar from 0 to 1. You can only use one of these four options at a time for creating a cross-validated tree: 'kfold', 'holdout', 'leaveout' and 'cvpartition'.

kfold

Number of folds to use in a cross-validated tree, a positive integer. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

Default: 10

leaveout

Use leave-one-out cross validation by setting to 'on'. You can only use one of these four options at a time: 'kfold', 'holdout', 'leaveout', or 'cvpartition'.

MergeLeaves

When 'on', `RegressionTree` merges leaves that originate from the same parent node, and that give a sum of risk values greater or equal to the risk associated with the parent node. When 'off', `RegressionTree` does not merge leaves.

Default: 'on'

MinLeaf

Each leaf has at least `MinLeaf` observations per tree leaf. If you supply both `MinParent` and `MinLeaf`, `RegressionTree` uses the setting that gives larger leaves: $\text{MinParent} = \max(\text{MinParent}, 2 * \text{MinLeaf})$.

Default: 1

MinParent

Each branch node in the tree has at least `MinParent` observations. If you supply both `MinParent` and `MinLeaf`, `RegressionTree` uses the setting that gives larger leaves: $\text{MinParent} = \max(\text{MinParent}, 2 * \text{MinLeaf})$.

Default: 10

NVarToSample

Number of predictors to select at random for each split. Can be a positive integer or 'all', which means use all available predictors.

Default: 'all'

PredictorNames

A cell array of names for the predictor variables, in the order in which they appear in `X`.

Default: {'x1', 'x2', ...}

Prune

When 'on', `RegressionTree` computes the full tree and the optimal sequence of pruned subtrees. When 'off' `RegressionTree` computes the full tree without pruning.

RegressionTree

Default: 'on'

PruneCriterion

String with the pruning criterion, always 'error'.

Default: 'error'

ResponseName

Name of the response variable Y, a string.

Default: 'Y'

ResponseTransform

Function handle for transforming the raw response values (mean squared error). The function handle should accept a matrix of response values and return a matrix of the same size. The default string 'none' means $@(x)x$, or no transformation.

Add or change a ResponseTransform function by dot addressing:

```
tree.ResponseTransform = @function
```

Default: 'none'

SplitCriterion

Criterion for choosing a split, always the string 'MSE', meaning mean squared error.

Default: 'MSE'

Weights

Vector of observation weights. The length of `weights` is the number of rows in `X`.

Default: `ones(size(X,1),1)`

Properties

CategoricalPredictors

List of categorical predictors, a numeric vector with indices from 1 to p , where p is the number of columns of X .

CatSplit

An n -by-2 cell array, where n is the number of categorical splits in `tree`. Each row in `CatSplit` gives left and right values for a categorical split. For each branch node with categorical split j based on a categorical predictor variable z , the left child is chosen if z is in `CatSplit(j,1)` and the right child is chosen if z is in `CatSplit(j,2)`. The splits are in the same order as nodes of the tree. Nodes for these splits can be found by running `cuttype` and selecting 'categorical' cuts from top to bottom.

Children

An n -by-2 array containing the numbers of the child nodes for each node in `tree`, where n is the number of nodes. Leaf nodes have child node 0.

CutCategories

An n -by-2 cell array of the categories used at branches in `tree`, where n is the number of nodes. For each branch node i based on a categorical predictor variable x , the left child is chosen if x is among the categories listed in `CutCategories{i,1}`, and the right child is chosen if x is among those listed in `CutCategories{i,2}`. Both columns of `CutCategories` are empty for branch nodes based on continuous predictors and for leaf nodes.

`CutVar` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

CutPoint

An n -element vector of the values used as cut points in `tree`, where n is the number of nodes. For each branch node i based on a continuous predictor variable x , the left child is chosen if $x < \text{CutPoint}(i)$ and the right child is chosen if $x \geq \text{CutPoint}(i)$.

RegressionTree

CutPoint is NaN for branch nodes based on categorical predictors and for leaf nodes.

CutType

An n -element cell array indicating the type of cut at each node in `tree`, where n is the number of nodes. For each node i , `CutType{i}` is:

- 'continuous' — If the cut is defined in the form $x < v$ for a variable x and cut point v .
- 'categorical' — If the cut is defined by whether a variable x takes a value in a set of categories.
- '' — If i is a leaf node.

`CutVar` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

CutVar

An n -element cell array of the names of the variables used for branching in each node in `tree`, where n is the number of nodes. These variables are sometimes known as *cut variables*. For leaf nodes, `CutVar` contains an empty string.

`CutVar` contains the cut points for 'continuous' cuts, and `CutCategories` contains the set of categories.

IsBranch

An n -element logical vector `ib` that is `true` for each branch node and `false` for each leaf node of `tree`.

ModelParams

Object holding parameters of `tree`.

NObservations

Number of observations in the training data, a numeric scalar. `NObservations` can be less than the number of rows of input data `X` when there are missing values in `X` or response `Y`.

NodeErr

An n -element vector `e` of the errors of the nodes in `tree`, where n is the number of nodes. `e(i)` is the misclassification probability for node `i`.

NodeMean

An n -element numeric array with mean values in each node of `tree`, where n is the number of nodes in the tree. Every element in `NodeMean` is the average of the true `Y` values over all observations in the node.

NodeProb

An n -element vector `p` of the probabilities of the nodes in `tree`, where n is the number of nodes. The probability of a node is computed as the proportion of observations from the original data that satisfy the conditions for the node. This proportion is adjusted for any prior probabilities assigned to each class.

NodeSize

An n -element vector `sizes` of the sizes of the nodes in `tree`, where n is the number of nodes. The size of a node is defined as the number of observations from the data used to create the tree that satisfy the conditions for the node.

NumNodes

The number of nodes n in `tree`.

Parent

An n -element vector `p` containing the number of the parent node for each node in `tree`, where n is the number of nodes. The parent of the root node is 0.

PredictorNames

RegressionTree

A cell array of names for the predictor variables, in the order in which they appear in `X`.

PruneList

An n -element numeric vector with the pruning levels in each node of `tree`, where n is the number of nodes.

ResponseName

Name of the response variable `Y`, a string.

ResponseTransform

Function handle for transforming the raw response values (mean squared error). The function handle should accept a matrix of response values and return a matrix of the same size. The default string 'none' means `@(x)x`, or no transformation.

Add or change a `ResponseTransform` function by dot addressing:

```
tree.ResponseTransform = @function
```

Risk

An n -element vector `r` of the risk of the nodes in `tree`, where n is the number of nodes. The risk `r(i)` for node `i` is the node error `NodeErr(i)` multiplied by the node probability `NodeProb(i)`.

SurrCutCategories

An n -element cell array of the categories used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node `k`, `SurrCutCategories{k}` is a cell array. The length of `SurrCutCategories{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutCategories{k}` is either an empty string for a continuous surrogate predictor, or is a two-element cell array with categories for a categorical surrogate predictor. The first element of this two-element cell array lists categories assigned to the left child by this surrogate split, and the second element of this two-element cell array lists categories assigned to the right child by this

surrogate split. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutCategories` contains an empty cell.

SurrCutFlip

An n -element cell array of the numeric cut assignments used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutFlip{k}` is a numeric vector. The length of `SurrCutFlip{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutFlip{k}` is either zero for a categorical surrogate predictor, or a numeric cut assignment for a continuous surrogate predictor. The numeric cut assignment can be either -1 or $+1$. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and the cut assignment for this surrogate split is $+1$, or if $Z \geq C$ and the cut assignment for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and the cut assignment for this surrogate split is $+1$, or if $Z < C$ and the cut assignment for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutFlip` contains an empty array.

SurrCutPoint

An n -element cell array of the numeric values used for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutPoint{k}` is a numeric vector. The length of `SurrCutPoint{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrCutPoint{k}` is either NaN for a categorical surrogate predictor, or a numeric cut for a continuous surrogate predictor. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and `SurrCutFlip` for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and `SurrCutFlip` for this surrogate split is $+1$, or if $Z < C$ and `SurrCutFlip` for this

surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables returned by `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutPoint` contains an empty cell.

SurrCutType

An n -element cell array indicating types of surrogate splits at each node in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrCutType{k}` is a cell array with the types of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The order of the surrogate split variables at each node is matched to the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutType` contains an empty cell. A surrogate split type can be either 'continuous' if the cut is defined in the form $Z < V$ for a variable Z and cut point V or 'categorical' if the cut is defined by whether Z takes a value in a set of categories.

SurrCutVar

An n -element cell array of the names of the variables used for surrogate splits in each node in `tree`, where n is the number of nodes in `tree`. Every element of `SurrCutVar` is a cell array with the names of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrCutVar` contains an empty cell.

SurrVarAssoc

An n -element cell array of the predictive measures of association for surrogate splits in `tree`, where n is the number of nodes in `tree`. For each node k , `SurrVarAssoc{k}` is a numeric vector. The

length of `SurrVarAssoc{k}` is equal to the number of surrogate predictors found at this node. Every element of `SurrVarAssoc{k}` gives the predictive measure of association between the optimal split and this surrogate split. The order of the surrogate split variables at each node is the order of variables in `SurrCutVar`. The optimal-split variable at this node does not appear. For nonbranch (leaf) nodes, `SurrVarAssoc` contains an empty cell.

W

The scaled **weights**, a vector with length `n`, the number of rows in `X`.

X

A matrix of predictor values. Each column of `X` represents one variable, and each row represents one observation.

Y

A numeric column vector with the same number of rows as `X`. Each entry in `Y` is the response to the data in the corresponding row of `X`.

Methods

<code>compact</code>	Compact regression tree
<code>crossval</code>	Cross-validated decision tree
<code>cvloss</code>	Regression error by cross validation
<code>fit</code>	Binary decision tree for regression
<code>prune</code>	Produce sequence of subtrees by pruning
<code>resubLoss</code>	Regression error by resubstitution
<code>resubPredict</code>	Predict resubstitution response of tree
<code>template</code>	Create regression template

RegressionTree

Inherited Methods

loss	Regression error
meanSurrVarAssoc	Mean predictive measure of association for surrogate splits in decision tree
predict	Predict response of regression tree
predictorImportance	Estimates of predictor importance
view	View tree

Copy Semantics

Value. To learn how value classes affect copy operations, see Copying Objects in the MATLAB Programming Fundamentals documentation.

Examples

Load the data in `carsmall.mat`, and make a regression tree to predict the mileage of cars based on their weights and numbers of cylinders:

```
load carsmall
tree = RegressionTree.fit([Weight, Cylinders],MPG,...
    'categoricalpredictors',2,'MinParent',20,...
    'PredictorNames',{'W','C'})

tree =

RegressionTree:
    PredictorNames: {'W' 'C'}
    CategoricalPredictors: 2
    ResponseName: 'Response'
    ResponseTransform: 'none'
                X: [94x2 double]
                Y: [94x1 double]
                W: [94x1 double]
    ModelParams: [1x1 classreg.learning.modelparams.TreeParams]
```

Predict the mileage of 4,000-pound cars with 4, 6, and 8 cylinders:

```
mileage4K = predict(tree,[4000 4; 4000 6; 4000 8])
```

```
mileage4K =  
 19.2778  
 19.2778  
 14.3889
```

See Also

[ClassificationTree](#) | [RegressionEnsemble](#) | [RegressionTree.fit](#) | [CompactRegressionTree](#) | [predict](#)

Tutorials

- “Classification Trees and Regression Trees” on page 13-30

regstats

Purpose Regression diagnostics

Syntax

```
regstats(y,X,model)
stats = regstats(...)
stats = regstats(y,X,model,whichstats)
```

Description `regstats(y,X,model)` performs a multilinear regression of the responses in `y` on the predictors in `X`. `X` is an n -by- p matrix of p predictors at each of n observations. `y` is an n -by-1 vector of observed responses.

Note By default, `regstats` adds a first column of 1s to `X`, corresponding to a constant term in the model. Do not enter a column of 1s directly into `X`.

The optional input `model` controls the regression model. By default, `regstats` uses a linear additive model with a constant term. `model` can be any one of the following strings:

- 'linear' — Constant and linear terms (the default)
- 'interaction' — Constant, linear, and interaction terms
- 'quadratic' — Constant, linear, interaction, and squared terms
- 'purequadratic' — Constant, linear, and squared terms

Alternatively, `model` can be a matrix of model terms accepted by the `x2fx` function. See `x2fx` for a description of this matrix and for a description of the order in which terms appear. You can use this matrix to specify other models including ones without a constant term.

With this syntax, the function displays a graphical user interface (GUI) with a list of diagnostic statistics, as shown in the following figure.

Regstats Export to Workspace [-] [□] [×]

<input type="checkbox"/> Q from QR Decomposition	Q
<input type="checkbox"/> R from QR Decomposition	R
<input type="checkbox"/> Coefficients	beta
<input type="checkbox"/> Coefficient Covariance	covb
<input type="checkbox"/> Fitted Values	yhat
<input type="checkbox"/> Residuals	r
<input type="checkbox"/> Mean Square Error	mse
<input type="checkbox"/> R-square Statistic	rsquare
<input type="checkbox"/> Adjusted R-square Statistic	adjrsquare
<input type="checkbox"/> Leverage	leverage
<input type="checkbox"/> Hat Matrix	hatmat
<input type="checkbox"/> Delete-1 Variance	s2_i
<input type="checkbox"/> Delete-1 Coefficients	beta_i
<input type="checkbox"/> Standardized Residuals	standres
<input type="checkbox"/> Studentized Residuals	studres
<input type="checkbox"/> Change in Beta	dfbetas
<input type="checkbox"/> Change in Fitted Value	dffit
<input type="checkbox"/> Scaled Change in Fit	dffits
<input type="checkbox"/> Change in Covariance	cowratio
<input type="checkbox"/> Cook's Distance	cookd
<input type="checkbox"/> t Statistics	tstat
<input type="checkbox"/> F Statistic	fstat
<input type="checkbox"/> DW Statistic	dwstat

OK **Cancel** **Help**

regstats

When you select check boxes corresponding to the statistics you want to compute and click **OK**, `regstats` returns the selected statistics to the MATLAB workspace. The names of the workspace variables are displayed on the right-hand side of the interface. You can change the name of the workspace variable to any valid MATLAB variable name.

`stats = regstats(...)` creates the structure `stats`, whose fields contain all of the diagnostic statistics for the regression. This syntax does not open the GUI. The fields of `stats` are listed in the following table.

Field	Description
Q	Q from the QR decomposition of the design matrix
R	R from the QR decomposition of the design matrix
beta	Regression coefficients
covb	Covariance of regression coefficients
yhat	Fitted values of the response data
r	Residuals
mse	Mean squared error
rsquare	R^2 statistic
adjrsquare	Adjusted R^2 statistic
leverage	Leverage
hatmat	Hat matrix
s2_i	Delete-1 variance
beta_i	Delete-1 coefficients
standres	Standardized residuals
studres	Studentized residuals
dfbetas	Scaled change in regression coefficients
dffit	Change in fitted values

Field	Description
dffits	Scaled change in fitted values
covratio	Change in covariance
cookd	Cook's distance
tstat	t statistics and p -values for coefficients
fstat	F statistic and p -value
dwstat	Durbin-Watson statistic and p -value

Note that the fields names of `stats` correspond to the names of the variables returned to the MATLAB workspace when you use the GUI. For example, `stats.beta` corresponds to the variable `beta` that is returned when you select **Coefficients** in the GUI and click **OK**.

`stats = regstats(y,X,model,whichstats)` returns only the statistics that you specify in `whichstats`. `whichstats` can be a single string such as `'leverage'` or a cell array of strings such as `{'leverage' 'standres' 'studres'}`. Set `whichstats` to `'all'` to return all of the statistics.

Note The F statistic is computed under the assumption that the model contains a constant term. It is not correct for models without a constant. The R^2 statistic can be negative for models without a constant, which indicates that the model is not appropriate for the data.

Examples

Open the `regstats` GUI using data from `hald.mat`:

```
load hald
regstats(heat,ingredients,'linear');
```

Select **Fitted Values** and **Residuals** in the GUI:



Click **OK** to export the fitted values and residuals to the MATLAB workspace in variables named `yhat` and `r`, respectively.

You can create the same variables using the `stats` output, without opening the GUI:

```
whichstats = {'yhat','r'};  
stats = regstats(heat,ingredients,'linear',whichstats);  
yhat = stats.yhat;  
r = stats.r;
```

References

- [1] Belsley, D. A., E. Kuh, and R. E. Welsch. *Regression Diagnostics*. Hoboken, NJ: John Wiley & Sons, Inc., 1980.
- [2] Chatterjee, S., and A. S. Hadi. “Influential Observations, High Leverage Points, and Outliers in Linear Regression.” *Statistical Science*. Vol. 1, 1986, pp. 379–416.
- [3] Cook, R. D., and S. Weisberg. *Residuals and Influence in Regression*. New York: Chapman & Hall/CRC Press, 1983.
- [4] Goodall, C. R. “Computation Using the QR Decomposition.” *Handbook in Statistics*. Vol. 9, Amsterdam: Elsevier/North-Holland, 1993.

See Also

[LinearModel](#) | [LinearModel.fit](#) | [LinearModel.stepwise](#) |

Related Examples

- “Interpret Linear Regression Results” on page 9-60
- “Linear Regression Workflow” on page 9-40

Concepts

- “Linear Regression Output and Diagnostic Statistics” on page 9-68

Purpose Find weights to minimize resubstitution error plus penalty term

Syntax
`ens1 = regularize(ens)`
`ens1 = regularize(ens,Name,Value)`

Description
`ens1 = regularize(ens)` finds optimal weights for learners in `ens` by lasso regularization. `regularize` returns a regression ensemble identical to `ens`, but with a populated `Regularization` property.
`ens1 = regularize(ens,Name,Value)` computes optimal weights with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments
ens
A regression ensemble, created by `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

lambda

Vector of nonnegative regularization parameter values for lasso. For the default setting of `lambda`, `regularize` calculates the smallest value `lambda_max` for which all optimal weights for learners are 0. The default value of `lambda` is a vector including 0 and nine exponentially-spaced numbers from `lambda_max/1000` to `lambda_max`.

Default: `[0
logspace(log10(lambda_max/1000),log10(lambda_max),9)]`

npass

RegressionEnsemble.regularize

Maximal number of passes for lasso optimization, a positive integer.

Default: 10

reltol

Relative tolerance on the regularized loss for lasso, a numeric positive scalar.

Default: 1e-3

verbose

Verbosity level, either 0 or 1. When set to 1, `regularize` displays more information as it runs.

Default: 0

Output Arguments

ens1

A regression ensemble. Usually you set `ens1` to the same name as `ens`.

Definitions

Lasso

The lasso algorithm finds an optimal set of learner weights α_t that minimize

$$\sum_{n=1}^N w_n g \left(\left(\sum_{t=1}^T \alpha_t h_t(x_n) \right), y_n \right) + \lambda \sum_{t=1}^T |\alpha_t|.$$

Here

- $\lambda \geq 0$ is a parameter you provide, called the lasso parameter.
- h_t is a weak learner in the ensemble trained on N observations with predictors x_n , responses y_n , and weights w_n .

- $g(f,y) = (f - y)^2$ is the squared error.

Examples

Regularize an ensemble of bagged trees:

```
X = rand(2000,20);
Y = repmat(-1,2000,1);
Y(sum(X(:,1:5),2)>2.5) = 1;
bag = fitensemble(X,Y,'Bag',300,'Tree',...
    'type','regression');
bag = regularize(bag,'lambda',[0.001 0.1],'verbose',1);
```

regularize reports on its progress.

To see the resulting regularization structure:

```
bag.Regularization
ans =
    Method: 'Lasso'
    TrainedWeights: [300x2 double]
    Lambda: [1.0000e-003 0.1000]
    ResubstitutionMSE: [0.0616 0.0812]
    CombineWeights: @classreg.learning.combiner.WeightedSum
```

See how many learners in the regularized ensemble have positive weights (so would be included in a shrunken ensemble):

```
sum(bag.Regularization.TrainedWeights > 0)
```

```
ans =
    116    91
```

To shrink the ensemble using the weights from Lambda = 0.1:

```
cmp = shrink(bag,'weightcolumn',2)
```

```
cmp =
```

```
classreg.learning.regr.CompactRegressionEnsemble:
    PredictorNames: {1x20 cell}
```

RegressionEnsemble.regularize

```
CategoricalPredictors: []  
  ResponseName: 'Y'  
  ResponseTransform: 'none'  
    NTrained: 91
```

There are 91 members in the regularized ensemble, which is less than 1/3 of the original 300.

See Also

[shrink](#) | [cvshrink](#) | [lasso](#)

Tutorials

- “Ensemble Regularization” on page 13-98

gmdistribution.RegV property

Purpose

Value of 'Regularize' parameter

Description

The value of the parameter 'Regularize'.

Note This property applies only to gmdistribution objects constructed with `fit`.

relieff

Purpose

Importance of attributes (predictors) using ReliefF algorithm

Syntax

```
[RANKED,WEIGHT] = relieff(X,Y,K)
[RANKED,WEIGHT] = relieff(X,Y,K, 'PARAM1',val1, 'PARAM2',val2,
    ...)
```

Description

[RANKED,WEIGHT] = relieff(X,Y,K) computes ranks and weights of attributes (predictors) for input data matrix X and response vector Y using the ReliefF algorithm for classification or RReliefF for regression with K nearest neighbors. For classification, relieff uses K nearest neighbors per class. RANKED are indices of columns in X ordered by attribute importance, meaning RANKED(1) is the index of the most important predictor. WEIGHT are attribute weights ranging from -1 to 1 with large positive weights assigned to important attributes.

If Y is numeric, relieff by default performs RReliefF analysis for regression. If Y is categorical, logical, a character array, or a cell array of strings, relieff by default performs ReliefF analysis for classification.

Attribute ranks and weights computed by relieff usually depend on K . If you set K to 1, the estimates computed by relieff can be unreliable for noisy data. If you set K to a value comparable with the number of observations (rows) in X , relieff can fail to find important attributes. You can start with $K = 10$ and investigate the stability and reliability of relieff ranks and weights for various values of K .

```
[RANKED,WEIGHT] =
relieff(X,Y,K, 'PARAM1',val1, 'PARAM2',val2,...) specifies
optional parameter name/value pairs.
```

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name, Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1, Value1, ..., NameN, ValueN.

method

Either 'regression' (default if Y is numeric) or 'classification' (default if Y is not numeric).

prior

Prior probabilities for each class, specified as a string ('empirical' or 'uniform') or as a vector (one value for each distinct group name) or as a structure S with two fields:

- S.group containing the group names as a categorical variable, character array, or cell array of strings
- S.prob containing a vector of corresponding probabilities

If the input value is 'empirical' (default), class probabilities are determined from class frequencies in Y. If the input value is 'uniform', all class probabilities are set equal.

updates

Number of observations to select at random for computing the weight of every attribute. By default all observations are used.

categoricalx

'on' or 'off', 'off' by default. If 'on', treat all predictors in X as categorical. If 'off', treat all predictors in X as numerical. You cannot mix numerical and categorical predictors.

sigma

Distance scaling factor. For observation i , influence on the attribute weight from its nearest neighbor j is multiplied by $\exp(-\text{rank}(i,j)/\text{sigma}^2)$, where $\text{rank}(i,j)$ is the position of j in the list of nearest neighbors of i sorted by distance in the ascending order. Default is Inf (all nearest neighbors have the same influence) for classification and 50 for regression.

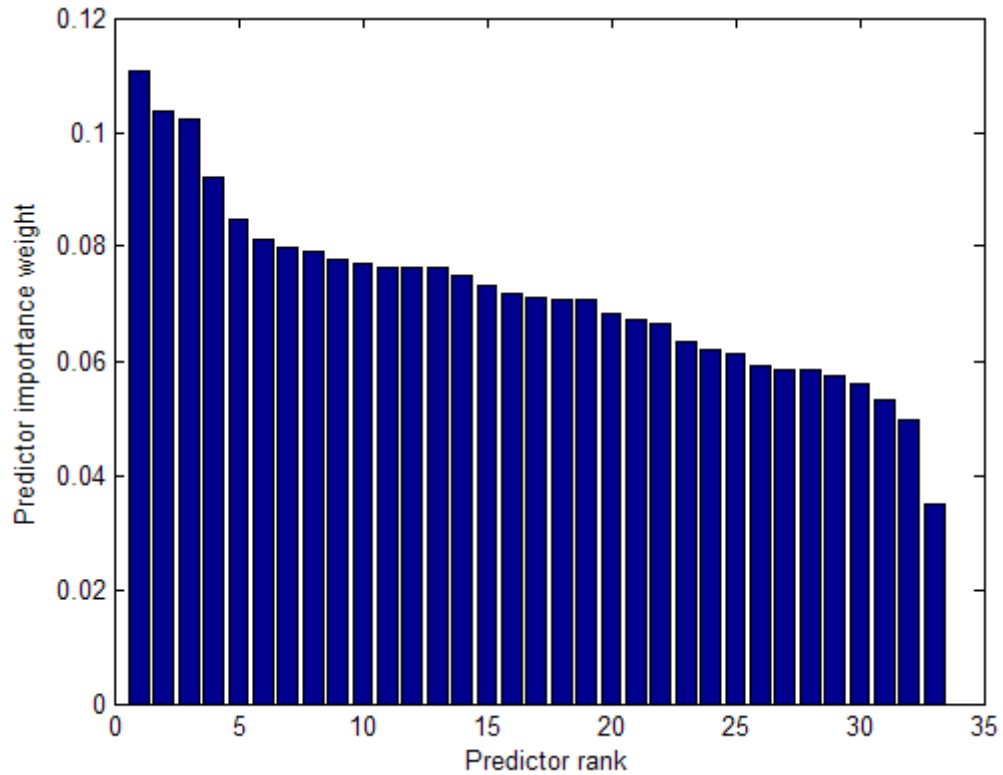
Examples

Identify important predictors in the ionosphere dataset:

```
load ionosphere;
```

relieff

```
[ranked,weights] = relieff(X,Y,10);  
bar(weights(ranked));  
xlabel('Predictor rank');  
ylabel('Predictor importance weight');
```



Examine the Fisher iris data to find the important predictors:

```
load fisheriris  
[ranked,weight] = relieff(meas,species,10)
```

```
ranked =
```

	4	3	1	2
weight =	0.1399	0.1226	0.3590	0.3754

The fourth predictor is the most important, and the second predictor is the least important.

References

- [1] Kononenko, I., Simec, E., & Robnik-Sikonja, M. (1997). *Overcoming the myopia of inductive learning algorithms with RELIEFF*. Retrieved from CiteSeerX: <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.56.4740>
- [2] Robnik-Sikonja, M., & Kononenko, I. (1997). *An adaptation of Relief for attribute estimation in regression*. Retrieved from CiteSeerX: <http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.34.8381>
- [3] Robnik-Sikonja, M., & Kononenko, I. (2003). *Theoretical and empirical analysis of ReliefF and RReliefF*. *Machine Learning*, 53, 23–69.

See Also

knnsearch | pdist2

CompactClassificationEnsemble.removeLearners

Purpose Remove members of compact classification ensemble

Syntax `cens1 = removeLearners(cens,idx)`

Description `cens1 = removeLearners(cens,idx)` creates a compact classification ensemble identical to `cens` only without the ensemble members in the `idx` vector.

- Tips**
- Typically, set `cens1` equal to `cens` to retain just one ensemble.
 - Removing learners reduces the memory used by the ensemble and speeds up its predictions.

Input Arguments

cens

Compact classification ensemble, constructed with `compact`.

idx

Vector of positive integers with entries from 1 to `cens.NTrained`, where `cens.NTrained` is the number of members in `cens`. `cens1` contains all members of `cens` except those with indices in `idx`.

Typically, you set `idx = j:cens.NTrained` for some positive integer `j`.

Output Arguments

cens1

Compact classification ensemble, identical to `cens` except `cens1` does not contain those members of `cens` with indices in `idx`.

Examples

Remove Learners from an Ensemble

Create a compact classification ensemble. Compact it further by removing members of the ensemble.

Create a compact classification ensemble for the ionosphere data.

```
load ionosphere
ens = fitensemble(X,Y,'AdaBoostM1',100,'Tree');
```

CompactClassificationEnsemble.removeLearners

```
cens = compact(ens);
```

Remove the last 50 members of the ensemble.

```
idx = cens.NTrained-49:cens.NTrained;  
cens1 = removeLearners(cens,idx);
```

See Also CompactClassificationEnsemble |

Related Examples

- “Classification with Imbalanced Data” on page 13-71

CompactRegressionEnsemble.removeLearners

Purpose Remove members of compact regression ensemble

Syntax `cens1 = removeLearners(cens,idx)`

Description `cens1 = removeLearners(cens,idx)` creates a compact regression ensemble identical to `cens` only without the ensemble members in the `idx` vector.

- Tips**
- Typically, set `cens1` equal to `cens` to retain just one ensemble.
 - Removing learners reduces the memory used by the ensemble and speeds up its predictions.

Input Arguments

cens
Compact regression ensemble, constructed with `compact`.

idx
Vector of positive integers with entries from 1 to `cens.NTrained`, where `cens.NTrained` is the number of members in `cens`. `cens1` contains the members of `cens` except those with indices in `idx`.
Typically, you set `idx = j:cens.NTrained` for some positive integer `j`.

Output Arguments

cens1
Compact regression ensemble, identical to `cens` except `cens1` does not contain members of `cens` with indices in `idx`.

Examples **Remove Learners from an Ensemble**

Create a compact regression ensemble. Compact it further by removing members of the ensemble.

Create a compact regression ensemble for the `carsmall` data.

```
load carsmall
X = [Weight Cylinders];
```


CompactRegressionEnsemble.removeLearners

```
ens = fitensemble(X,MPG,'LSBoost',100,'Tree','categorical',2);
cens = compact(ens);
```

Remove the last 50 members of the ensemble.

```
idx = cens.NTrained-49:cens.NTrained;
cens1 = removeLearners(cens,idx);
```

See Also [CompactRegressionEnsemble](#) |

GeneralizedLinearModel.removeTerms

Purpose Remove terms from generalized linear model

Syntax `mdl1 = removeTerms(mdl, terms)`

Description `mdl1 = removeTerms(mdl, terms)` returns a linear model the same as `mdl` but with fewer terms.

Input Arguments

mdl

Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

terms

Terms to remove from the `mdl` regression model. Specify as either a:

- Text string representing one or more terms to remove. For details, see “Wilkinson Notation” on page 20-2089.
- Row or rows in the terms matrix (see `modelspec` in `LinearModel.fit`). For example, if there are three variables A, B, and C:

```
[0 0 0] represents a constant term or intercept  
[0 1 0] represents B; equivalently, A^0 * B^1 * C^0  
[1 0 1] represents A*C  
[2 0 0] represents A^2  
[0 1 2] represents B*(C^2)
```

Output Arguments

mdl1

Generalized linear model, the same as `mdl` but without the terms given in `terms`. You can set `mdl1` equal to `mdl` to overwrite `mdl`.

Definitions

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k , where k is a positive integer	A, A^2, \dots, A^k
$A+B$	A, B
$A*B$	$A, B, A*B$
$A:B$	$A*B$ only
$-B$	Do not include B
$A*B+C$	$A, B, C, A*B$
$A+B+C+A:B$	$A, B, C, A*B$
$A*B*C - A:B:C$	$A, B, C, A*B, A*C, B*C$
$A*(B + C)$	$A, B, C, A*B, A*C$

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using `-1`.

For details, see Wilkinson and Rogers [1].

Examples

Remove a Term from a Generalized Linear Regression Model

This example makes a model using two predictors, then removes one.

Generate artificial data for the model, Poisson random numbers with two underlying predictors $X(1)$ and $X(2)$.

```
rng('default') % for reproducibility
rndvars = randn(100,2);
X = [2+rndvars(:,1),rndvars(:,2)];
mu = exp(1 + X*[1;2]);
```

GeneralizedLinearModel.removeTerms

```
y = poissrnd(mu);
```

Create a generalized linear regression model of Poisson data.

```
mdl = GeneralizedLinearModel.fit(X,y,...  
    'y ~ x1 + x2','distr','poisson')
```

```
mdl =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x1 + x2  
Distribution = Poisson
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	1.0405	0.022122	47.034	0
x1	0.9968	0.003362	296.49	0
x2	1.987	0.0063433	313.24	0

100 observations, 97 error degrees of freedom

Dispersion: 1

Chi^2-statistic vs. constant model: 2.95e+05, p-value = 0

Remove the second predictor from the model.

```
mdl1 = removeTerms(mdl,'x2')
```

```
mdl1 =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x1  
Distribution = Poisson
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
--	----------	----	-------	--------

GeneralizedLinearModel.removeTerms

(Intercept)	2.7784	0.014043	197.85	0
x1	1.1732	0.0033653	348.6	0

100 observations, 98 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 1.25e+05, p-value = 0

References

[1] Wilkinson, G. N., and C. E. Rogers. *Symbolic description of factorial models for analysis of variance*. J. Royal Statistics Society 22, pp. 392–399, 1973.

Alternatives

step adds or removes terms from a model using a greedy one-step algorithm.

See Also

addTerms | GeneralizedLinearModel | step |
GeneralizedLinearModel.stepwise |

Related Examples

- “Plots to Understand Predictor Effects and How to Modify a Model” on page 9-161
- “Generalized Linear Model Workflow” on page 9-171

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.removeTerms

Purpose Remove terms from linear model

Syntax `mdl1 = removeTerms(mdl, terms)`

Description `mdl1 = removeTerms(mdl, terms)` returns a linear model the same as `mdl` but with terms removed.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

terms

Terms to remove from the `mdl` regression model. Specify as either a:

- Text string representing one or more terms to remove. For details, see “Wilkinson Notation” on page 20-2093.
- Row or rows in the terms matrix (see `modelspec` in `LinearModel.fit`). For example, if there are three variables A, B, and C:

```
[0 0 0] represents a constant term or intercept  
[0 1 0] represents B; equivalently, A^0 * B^1 * C^0  
[1 0 1] represents A*C  
[2 0 0] represents A^2  
[0 1 2] represents B*(C^2)
```

Output Arguments

mdl1

Linear model, the same as `mdl` but with terms removed. You can set `mdl1` equal to `mdl` to overwrite `mdl`.

Definitions

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k , where k is a positive integer	A, A^2, \dots, A^k
$A+B$	A, B
$A*B$	$A, B, A*B$
$A:B$	$A*B$ only
$-B$	Do not include B
$A*B+C$	$A, B, C, A*B$
$A+B+C+A:B$	$A, B, C, A*B$
$A*B*C - A:B:C$	$A, B, C, A*B, A*C, B*C$
$A*(B + C)$	$A, B, C, A*B, A*C$

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using `-1`.

For details, see Wilkinson and Rogers [1].

Examples

Remove Terms from Model

Construct a default linear model of the Hald data. Remove terms with high p -values.

Load the data.

```
load hald
X = ingredients; % predictor variables
y = heat; % response
```

LinearModel.removeTerms

Fit a default linear model to the data.

```
mdl = LinearModel.fit(X,y)
```

```
mdl =
```

Linear regression model:

$$y \sim 1 + x1 + x2 + x3 + x4$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	62.405	70.071	0.8906	0.39913
x1	1.5511	0.74477	2.0827	0.070822
x2	0.51017	0.72379	0.70486	0.5009
x3	0.10191	0.75471	0.13503	0.89592
x4	-0.14406	0.70905	-0.20317	0.84407

Number of observations: 13, Error degrees of freedom: 8

Root Mean Squared Error: 2.45

R-squared: 0.982, Adjusted R-Squared 0.974

F-statistic vs. constant model: 111, p-value = 4.76e-07

Remove the x3 and x4 terms because their *p*-values are so high.

```
terms = 'x3 + x4'; % terms to remove
```

```
mdl1 = removeTerms(mdl, terms)
```

```
mdl1 =
```

Linear regression model:

$$y \sim 1 + x1 + x2$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	52.577	2.2862	22.998	5.4566e-10
x1	1.4683	0.1213	12.105	2.6922e-07
x2	0.66225	0.045855	14.442	5.029e-08

Number of observations: 13, Error degrees of freedom: 10
Root Mean Squared Error: 2.41
R-squared: 0.979, Adjusted R-Squared 0.974
F-statistic vs. constant model: 230, p-value = 4.41e-09

The new model has the same adjusted R-Squared value (0.974) as the previous model, meaning it is about as good a fit. All the terms in the new model have extremely low p -values.

References

[1] Wilkinson, G. N., and C. E. Rogers. *Symbolic description of factorial models for analysis of variance*. J. Royal Statistics Society 22, pp. 392–399, 1973.

Alternatives

Use `LinearModel.stepwise` to select a model from a starting model, continuing until no single step is beneficial.

Use `addTerms` to add particular terms.

Use `step` to optimally improve the model by adding or removing terms.

See Also

`addTerms` | `LinearModel` | `step` | `LinearModel.stepwise`

Tutorials

- “Change Models” on page 9-33

How To

- “Linear Regression” on page 9-7

categorical.reorderlevels

Purpose

Reorder levels

Syntax

```
B = reorderlevels(A,newlevels)
```

Description

`B = reorderlevels(A,newlevels)` reorders the levels of the categorical array `A`. `newlevels` is a cell array of strings or a 2-D character matrix that specifies the new order. `newlevels` must be a reordering of `getlabels(A)`.

The order of the levels of an ordinal array has significance for relational operators, minimum and maximum, and for sorting.

Examples

Reorder hockey standings:

```
standings = ordinal(1:3,{'Leafs','Canadiens','Bruins'});
getlabels(standings)
ans =
    'Leafs'    'Canadiens'    'Bruins'
```

```
standings = reorderlevels(standings,...
    {'Canadiens','Leafs','Bruins'});
getlabels(standings)
ans =
    'Canadiens'    'Leafs'    'Bruins'
```

See Also

`addlevels` | `droplevels` | `getlabels` | `islevel` | `mergelevels`

Purpose Repartition data for cross-validation

Syntax `cnew = repartition(c)`

Description `cnew = repartition(c)` constructs an object `cnew` of the `cvpartition` class defining a random partition of the same type as `c`, where `c` is also an object of the `cvpartition` class.

Repartitioning is useful for Monte-Carlo repetitions of cross-validation analyses. `repartition` is called by `crossval` when the `'mcreps'` parameter is specified.

Examples Partition and repartition 100 observations for 3-fold cross-validation:

```
c = cvpartition(100,'kfold',3)
c =
K-fold cross validation partition
      N: 100
  NumTestSets: 3
   TrainSize: 67 66 67
   TestSize: 33 34 33

cnew = repartition(c)
cnew =
K-fold cross validation partition
      N: 100
  NumTestSets: 3
   TrainSize: 67 66 67
   TestSize: 33 34 33
```

Check for equality of the test data in the first fold:

```
isequal(test(c,1),test(cnew,1))
ans =
     0
```

See Also `cvpartition`

dataset.replacdata

Purpose Replace dataset variables

Syntax

```
B = replacdata(A,X)
B = replacdata(A,X,vars)
B = replacdata(A,fun)
B = replacdata(A,fun,vars)
```

Description `B = replacdata(A,X)` creates a dataset array `B` with the same variables as the dataset array `A`, but with the data for those variables replaced by the data in the array `X`. `replacdata` creates each variable in `B` using one or more columns from `X`, in order. `X` must have as many columns as the total number of columns in all of the variables in `A`, and as many rows as `A` has observations.

`B = replacdata(A,X,vars)` creates a dataset array `B` with the same variables as the dataset array `A`, but with the data for the variables specified in `vars` replaced by the data in the array `X`. The remaining variables in `B` are copies of the corresponding variables in `A`. `vars` is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector. Each variable in `B` has as many columns as the corresponding variable in `A`. `X` must have as many columns as the total number of columns in all the variables specified in `vars`.

`B = replacdata(A,fun)` or `B = replacdata(A,fun,vars)` creates a dataset array `B` by applying the function `fun` to the values in `A`'s variables. `replacdata` first horizontally concatenates `A`'s variables into a single array, then applies the function `fun`. The specified variables in `A` must have types and sizes compatible with the concatenation. `fun` is a function handle that accepts a single input array and returns an array with the same number of rows and columns as the input.

Examples

```
data = dataset({rand(3,3),'Var1','Var2','Var3'})
```

```
% Use ZSCORE to normalize each variable in a dataset array
% separately, by explicitly extracting and transforming the
% data, and then replacing it.
```

```
X = double(data);
X = zscore(X);
data = replacedata(data,X)

% Equivalently, provide a handle to ZSCORE.
data = replacedata(data,@zscore)

% Use ZSCORE to normalize each observation in a dataset
% array separately by creating an anonymous function.
data = replacedata(data,@(x) zscore(x,[],2))
```

See Also

dataset

dataset.replaceWithMissing

Purpose Insert missing data indicators into a dataset array

Syntax `ds2 = replaceWithMissing(ds,Name,Value)`

Description `ds2 = replaceWithMissing(ds,Name,Value)` replaces specified values in a dataset array with standard missing data indicators using options specified by one or more `Name,Value` pair arguments. Use `replaceWithMissing` to specify:

- Which numeric missing value indicators to replace with NaN.
- Which string missing value indicators to replace with an empty string.
- Which categorical levels to replace with <undefined>.

Input Arguments

ds
dataset array.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

NumericValues

Vector of numeric values that `replaceWithMissing` replaces with NaN.

CategoricalLevels

String or cell array of strings naming the categorical levels that `replaceWithMissing` replaces with <undefined>.

Strings

String or cell array of strings containing the strings that `replaceWithMissing` replaces with the empty string, ''.

DataVars

Specified set of variables in `ds` for which `replaceWithMissing` replaces values. You can specify a positive integer or vector of positive integers indicating the variable column numbers, a variable name or a cell array of variables names, or a logical vector indicating which variables to replace missing values in.

Default: All variables in `ds`.

Output Arguments

`ds2`

dataset array that has the specified missing value indicators, in the specified variables of `ds`, replaced with standard missing value indicators.

Examples

Replace Nonstandard Missing Value Indicators

Replace nonstandard missing value indicators with standard missing value indicators.

Replace numeric missing values coded 99 with NaN, and string missing values coded '.' with the empty string.

```
ds = replaceWithMissing(ds,'NumericValues',99,'Strings','.');
```

See Also

[dataset](#) | [ismissing](#) |

Related Examples

- “Clean Messy and Missing Data” on page 2-138

Concepts

- “Dataset Arrays” on page 2-156

categorical repmat

Purpose Replicate and tile categorical array

Syntax
B = repmat(A,m,n)
B = repmat(A,[m n p ...])

Description B = repmat(A,m,n) creates a large array B consisting of an m-by-n tiling of copies of the categorical array A. The size of B is [size(A,1)*M size(A,2)*N, size(A,3), ...]. repmat(A,n) creates an n-by-n tiling.

B = repmat(A,[m n p ...]) tiles the categorical array A to produce a multidimensional array B composed of copies of A. The size of B is [size(A,1)*M, size(A,2)*N, size(A,3)*P, ...].

See Also ndims | size

Purpose Reset state

Syntax reset(q)

Description reset(q) resets the state of the quasi-random number stream q of the grandstream class back to its initial state, 1. Subsequent points drawn from the stream will be the same as those drawn from a new stream. The command is equivalent to q.State = 1.

Examples Use grandstream to construct a 3-D Halton stream, based on a point set that skips the first 1000 values and then retains every 101st point:

```
q = grandstream('halton',3,'Skip',1e3,'Leap',1e2)
q =
  Halton quasi-random stream in 3 dimensions
  Point set properties:
      Skip : 1000
      Leap : 100
      ScrambleMethod : none

nextIdx = q.State
nextIdx =
     1
```

Use grand to generate two samples of size four:

```
X1 = grand(q,4)
X1 =
    0.0928    0.3475    0.0051
    0.6958    0.2035    0.2371
    0.3013    0.8496    0.4307
    0.9087    0.5629    0.6166

nextIdx = q.State
nextIdx =
     5

X2 = grand(q,4)
```

grandstream.reset

```
X2 =  
    0.2446    0.0238    0.8102  
    0.5298    0.7540    0.0438  
    0.3843    0.5112    0.2758  
    0.8335    0.2245    0.4694  
nextIdx = q.State  
nextIdx =  
    9
```

Use reset to reset the stream, then generate another sample:

```
reset(q)  
nextIdx = q.State  
nextIdx =  
    1  
  
X = grand(q,4)  
X =  
    0.0928    0.3475    0.0051  
    0.6958    0.2035    0.2371  
    0.3013    0.8496    0.4307  
    0.9087    0.5629    0.6166
```

See Also

[grandstream](#) | [grand](#)

Purpose

Resize categorical array

Syntax

```
B = reshape(A,M,N)
B = reshape(A,m,n,p,...)
reshape(A,[m n p ...])
B = reshape(A,...,[],...)
```

Description

`B = reshape(A,M,N)` returns an m -by- n categorical matrix whose elements are taken columnwise from the categorical array `A`. An error results if `A` does not have $m*n$ elements.

`B = reshape(A,m,n,p,...)` or `reshape(A,[m n p ...])` returns an array with the same elements as `A` but reshaped to have the size m -by- n -by- p -by-... . $m*n*p*...$ must be the same as `numel(A)`.

`B = reshape(A,...,[],...)` calculates the length of the dimension represented by `[]`, such that the product of the dimensions equals `numel(A)`. `numel(A)` must be evenly divisible by the product of the known dimensions. You can use only one occurrence of `[]`.

In general, `reshape(A,siz)` returns an array with the same elements as `A` but reshaped to the size `siz`. `prod(siz)` must be the same as `numel(A)`.

See Also

`shiftdim` | `squeeze`

ClassificationDiscriminant.resubEdge

Purpose	Classification edge by resubstitution
Syntax	<code>edge = resubEdge(obj)</code>
Description	<code>edge = resubEdge(obj)</code> returns the classification edge obtained by <code>obj</code> on its training data.
Input Arguments	obj Discriminant analysis classifier, produced using <code>ClassificationDiscriminant.fit</code> .
Output Arguments	edge Classification edge obtained by resubstituting the training data into the calculation of <code>edge</code> .
Definitions	Edge The <i>edge</i> is the weighted mean value of the classification <i>margin</i> . The weights are the class probabilities in <code>obj.Prior</code> . If you supply weights in the <code>weights</code> name-value pair, those weights are normalized to sum to the prior probabilities in the respective classes, and are then used to compute the weighted average. Margin The classification <i>margin</i> is the difference between the classification <i>score</i> for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix <code>obj.X</code> . A high value of margin indicates a more reliable prediction than a low value. Score (discriminant analysis) For discriminant analysis, the <i>score</i> of a classification is the posterior probability of the classification. For the definition of posterior probability in discriminant analysis, see “Posterior Probability” on page 12-7.

Examples

Estimate the quality of a discriminant analysis classifier for the Fisher iris data by resubstitution:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
redge = resubEdge(obj)

redge =
    0.9454
```

See Also

[ClassificationDiscriminant](#) | [edge](#) | [resubMargin](#)

How To

- “Discriminant Analysis” on page 12-3

ClassificationEnsemble.resubEdge

Purpose Classification edge by resubstitution

Syntax
edge = resubEdge(ens)
edge = resubEdge(ens,Name,Value)

Description
edge = resubEdge(ens) returns the classification edge obtained by ens on its training data.
edge = resubEdge(ens,Name,Value) calculates edge with additional options specified by one or more Name,Value pair arguments. You can specify several name-value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

Input Arguments

ens
A classification ensemble created with fitensemble.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

learners

Indices of weak learners in the ensemble ranging from 1 to NTrained. resubEdge uses only these learners for calculating edge.

Default: 1:NTrained

mode

String representing the meaning of the output edge:

- 'ensemble' — edge is a scalar value, the loss for the entire ensemble.

- 'individual' — edge is a vector with one element per trained learner.
- 'cumulative' — edge is a vector in which element J is obtained by using learners 1:J from the input list of learners.

Default: 'ensemble'

Output Arguments

edge

Classification edge obtained by `ens` by resubstituting the training data into the calculation of edge. Classification edge is classification margin averaged over the entire data. `edge` can be a scalar or vector, depending on the setting of the `mode` name-value pair.

Definitions

Edge

The *edge* is the weighted mean value of the classification margin. The weights are the class probabilities in `ens.Prior`.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `ens.X`.

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

ClassificationEnsemble.resubEdge

Examples

Find the resubstitution edge for an ensemble that classifies the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
edge = resubEdge(ens)
```

```
edge =
    3.2486
```

See Also

[resubMargin](#) | [resubLoss](#) | [resubPredict](#) | [resubEdge](#)

Purpose	Edge of k -nearest neighbor classifier by resubstitution
Syntax	$E = \text{resubEdge}(\text{mdl})$
Description	$E = \text{resubEdge}(\text{mdl})$ returns the classification edge for mdl with the data used to train mdl (see “Edge” on page 20-2111).
Input Arguments	mdl k -nearest neighbor classifier, created by <code>ClassificationKNN.fit</code> .
Output Arguments	E Classification edge, a scalar that is the mean classification margin (see “Margin” on page 20-2111).
Definitions	Edge The <i>edge</i> is the mean value of the classification <i>margin</i> . Margin The classification <i>margin</i> is the difference between the classification <i>score</i> for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the training data. Score The <i>score</i> of a classification is the posterior probability of the classification. The posterior probability is the number of neighbors that have that classification, divided by the number of neighbors. For a more detailed definition that includes weights and prior probabilities, see “Posterior Probability” on page 20-1830.
Examples	Resubstitution Edge Calculation Construct a k -nearest neighbor classifier for the Fisher iris data, where $k = 5$.

ClassificationKNN.resubEdge

Load the data.

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',5);
```

Examine the resubstitution edge of the classifier.

```
E = resubEdge(mdl)
```

```
E =
```

```
0.9253
```

See Also

[ClassificationKNN](#) | [resubLoss](#) | [resubMargin](#) | [resubPredict](#) |

Related Examples

- “Examine the Quality of a KNN Classifier” on page 13-26

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

Purpose	Classification edge by resubstitution
Syntax	<code>edge = resubEdge(tree)</code>
Description	<code>edge = resubEdge(tree)</code> returns the classification edge obtained by <code>tree</code> on its training data.
Input Arguments	tree A classification tree created by <code>ClassificationTree.fit</code> .
Output Arguments	edge Classification edge obtained by resubstituting the training data into the calculation of <code>edge</code> .

Definitions

Edge

The *edge* is the weighted mean value of the classification margin. The weights are the class probabilities in `tree.Prior`.

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `X`.

Score (tree)

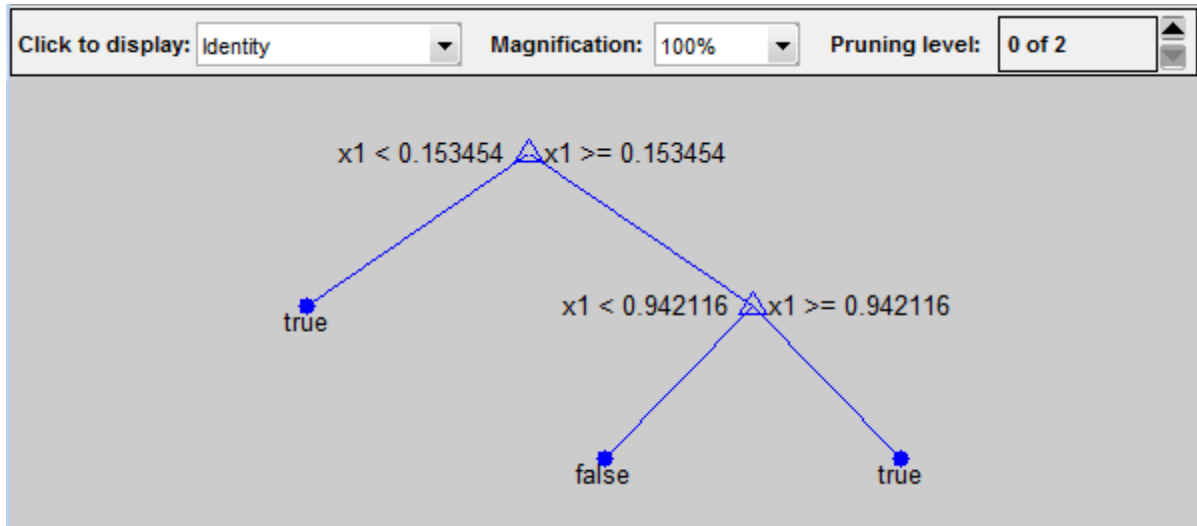
For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

For example, consider classifying a predictor `X` as true when `X < 0.15` or `X > 0.95`, and `X` is false otherwise.

ClassificationTree.resubEdge

Generate 100 random points and classify them:

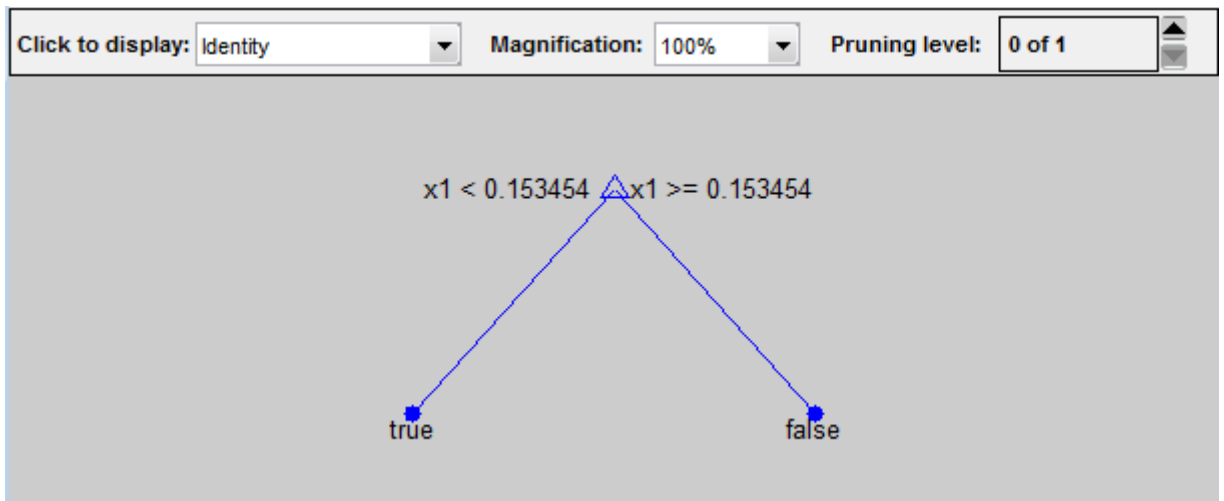
```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```



2

Prune the tree:

```
tree1 = prune(tree,'level',1);
view(tree1,'mode','graph')
```



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));  
[score X(1:10,:)]
```

```
ans =  
    0.9059    0.0941    0.8147  
    0.9059    0.0941    0.9058  
         0    1.0000    0.1270  
    0.9059    0.0941    0.9134  
    0.9059    0.0941    0.6324  
         0    1.0000    0.0975  
    0.9059    0.0941    0.2785
```

ClassificationTree.resubEdge

0.9059	0.0941	0.5469
0.9059	0.0941	0.9575
0.9059	0.0941	0.9649

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range $(.95, 1)$ instead of the expected 5 observations.

Examples

Estimate the quality of a classification tree for the Fisher iris data by resubstitution:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
redge = resubEdge(tree)

redge =
    0.9384
```

See Also

[edge](#) | [resubMargin](#) | [resubLoss](#) | [resubPredict](#)

Purpose

Classification error by resubstitution

Syntax

```
L = resubLoss(obj)
L = resubLoss(obj,Name,Value)
```

Description

`L = resubLoss(obj)` returns the resubstitution loss, meaning the loss computed for the data that `ClassificationDiscriminant.fit` used to create `obj`.

`L = resubLoss(obj,Name,Value)` returns loss statistics with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

obj

Discriminant analysis classifier, produced using `ClassificationDiscriminant.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

lossfun

Function handle or string representing a loss function. Built-in loss functions are:

- 'binodeviance' — See “Loss Functions” on page 20-2118.
- 'classiferror' — Fraction of misclassified observations. See “Loss Functions” on page 20-2118.
- 'exponential' — See “Loss Functions” on page 20-2118.
- 'mincost' — Smallest misclassification cost as given by the `obj.Cost` matrix.

ClassificationDiscriminant.resubLoss

You can write your own loss function using the syntax described in “Loss Functions” on page 20-2118.

Default: 'mincost'

Output Arguments

L

Classification error, a scalar. The meaning of the error depends on the values in `weights` and `lossfun`. See “Classification Error” on page 20-2118.

Definitions

Classification Error

The default classification error is the fraction of the training data X that `obj` misclassifies.

Weighted classification error is the sum of weight i times the Boolean value that is 1 when `obj` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

- 'classiferror' — Predict the label with the largest posterior probability. The loss is then the fraction of misclassified observations.

- 'mincost' — Predict the label with the smallest expected misclassification cost, with expectation taken over the posterior probability, and cost as given by the `Cost` property of the classifier (a matrix). The loss is then the true misclassification cost averaged over the observations.

To write your own loss function, create a function file in this form:

```
function loss = lossfun(C,S,W,COST)
```

- `N` is the number of rows of `X`.
- `K` is the number of classes in the classifier, represented in the `ClassNames` property.
- `C` is an `N`-by-`K` logical matrix, with one true per row for the true class. The index for each class is its position in the `ClassNames` property.
- `S` is an `N`-by-`K` numeric matrix. `S` is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from `predict`.
- `W` is a numeric vector with `N` elements, the observation weights. If you pass `W`, the elements are normalized to sum to the prior probabilities in the respective classes.
- `COST` is a `K`-by-`K` numeric matrix of misclassification costs. For example, you can use `COST = ones(K) - eye(K)`, which means a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

Posterior Probability

The posterior probability that a point z belongs to class j is the product of the prior probability and the multivariate normal density. The density function of the multivariate normal with mean μ_j and covariance Σ_j at a point z is

ClassificationDiscriminant.resubLoss

$$P(x | k) = \frac{1}{(2\pi |\Sigma_k|)^{1/2}} \exp\left(-\frac{1}{2}(x - \mu_k)^T \Sigma_k^{-1} (x - \mu_k)\right),$$

where $|\Sigma_k|$ is the determinant of Σ_k , and Σ_k^{-1} is the inverse matrix.

Let $P(k)$ represent the prior probability of class k . Then the posterior probability that an observation x is of class k is

$$\hat{P}(k | x) = \frac{P(x | k)P(k)}{P(x)},$$

where $P(x)$ is a normalization constant, the sum over k of $P(x | k)P(k)$.

Prior Probability

The prior probability is one of three choices:

- 'uniform' — The prior probability of class k is one over the total number of classes.
- 'empirical' — The prior probability of class k is the number of training samples of class k divided by the total number of training samples.
- Custom — The prior probability of class k is the k th element of the prior vector. See `ClassificationDiscriminant.fit`.

After creating a classifier `obj`, you can set the prior by dot addressing:

```
obj.Prior = v;
```

where `v` is a vector of positive elements representing the frequency with which each element occurs. You do not need to retrain the classifier when you set a new prior.

Cost

The matrix of expected costs per observation is defined in “Cost” on page 12-8.

Examples

Compute the resubstituted classification error for the Fisher iris data:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
L = resubLoss(obj)
```

```
L =
    0.0200
```

See Also

[ClassificationDiscriminant | loss](#)

How To

- “Discriminant Analysis” on page 12-3

ClassificationEnsemble.resubLoss

Purpose Classification error by resubstitution

Syntax
L = resubLoss(ens)
L = resubLoss(ens,Name,Value)

Description L = resubLoss(ens) returns the resubstitution loss, meaning the loss computed for the data that fitensemble used to create ens.

L = resubLoss(ens,Name,Value) calculates loss with additional options specified by one or more Name,Value pair arguments. You can specify several name-value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

Input Arguments

ens
A classification ensemble created with fitensemble.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name,Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1,Value1, ...,NameN,ValueN.

learners

Indices of weak learners in the ensemble ranging from 1 to NTrained. resubLoss uses only these learners for calculating loss.

Default: 1:NTrained

lossfun

Function handle or string representing a loss function. Built-in loss functions:

- 'binodeviance' — See “Loss Functions” on page 20-2123
- 'classiferror' — Fraction of misclassified data

- 'exponential' — See “Loss Functions” on page 20-2123

You can write your own loss function in the syntax described in “Loss Functions” on page 20-2123.

Default: 'classiferror'

mode

String representing the meaning of the output L:

- 'ensemble' — L is a scalar value, the loss for the entire ensemble.
- 'individual' — L is a vector with one element per trained learner.
- 'cumulative' — L is a vector in which element J is obtained by using learners 1:J from the input list of learners.

Default: 'ensemble'

Output Arguments

L

Loss, by default the fraction of misclassified data. L can be a vector, and can mean different things, depending on the name-value pair settings.

Definitions

Classification Error

The default classification error is the fraction of the training data X that `ens` misclassifies.

Weighted classification error is the sum of weight i times the Boolean value that is 1 when `tree` misclassifies the i th row of X, divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

ClassificationEnsemble.resubLoss

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'classiferror' — Fraction of misclassified data, weighted by w .
- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

To write your own loss function, create a function file of the form

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of `ens.X`.
- K is the number of classes in `ens`, represented in `ens.ClassNames`.
- C is an N -by- K logical matrix, with one `true` per row for the true class. The index for each class is its position in `tree.ClassNames`.
- S is an N -by- K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the `score` output from `predict`.
- W is a numeric vector with N elements, the observation weights.
- $COST$ is a K -by- K numeric matrix of misclassification costs. The default 'classiferror' gives a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

Examples

Compute the resubstitution loss for a classification ensemble for the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
loss = resubLoss(ens)
```

```
loss =
    0.0333
```

See Also

[resubEdge](#) | [resubMargin](#) | [resubPredict](#) | [resubLoss](#)

ClassificationKNN.resubLoss

Purpose Loss of k -nearest neighbor classifier by resubstitution

Syntax `L = resubLoss mdl`
`L = resubLoss mdl, Name, Value`

Description `L = resubLoss mdl` returns the resubstitution loss, meaning the loss computed for the data that `ClassificationKNN.fit` used to create `mdl`.
`L = resubLoss mdl, Name, Value` returns loss statistics with additional options specified by one or more `Name, Value` pair arguments.

Input Arguments **mdl**
k-nearest neighbor classifier, created by `ClassificationKNN.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

lossfun

Function handle or string representing a loss function. Built-in loss functions are:

- 'binodeviance' — See “Loss Functions” on page 20-2127.
- 'classiferror' — Fraction of misclassified observations. See “Loss Functions” on page 20-2127.
- 'exponential' — See “Loss Functions” on page 20-2127.
- 'mincost' — Smallest misclassification cost as given by the `mdl.Cost` matrix.

You can write your own loss function using the syntax described in “Loss Functions” on page 20-2127.

Default: 'mincost'

Output Arguments

L

Classification error, a scalar. The meaning of the error depends on the values in `weights` and `lossfun`. See “Classification Error” on page 20-2127.

Definitions

Classification Error

The default classification error is the fraction of data X that `mdl` misclassifies, where Y represents the true classifications.

The weighted classification error is the sum of weight i times the Boolean value that is 1 when `mdl` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

- 'classiferror' — Predict the label with the largest posterior probability. The loss is then the fraction of misclassified observations.

ClassificationKNN.resubLoss

- 'mincost' — Predict the label with the smallest expected misclassification cost, with expectation taken over the posterior probability, and cost as given by the `Cost` property of the classifier (a matrix). The loss is then the true misclassification cost averaged over the observations.

To write your own loss function, create a function file in this form:

```
function loss = lossfun(C,S,W,COST)
```

- `N` is the number of rows of `X`.
- `K` is the number of classes in the classifier, represented in the `ClassNames` property.
- `C` is an `N`-by-`K` logical matrix, with one true per row for the true class. The index for each class is its position in the `ClassNames` property.
- `S` is an `N`-by-`K` numeric matrix. `S` is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from `predict`.
- `W` is a numeric vector with `N` elements, the observation weights. If you pass `W`, the elements are normalized to sum to the prior probabilities in the respective classes.
- `COST` is a `K`-by-`K` numeric matrix of misclassification costs. For example, you can use `COST = ones(K) - eye(K)`, which means a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

True Misclassification Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation.

You can set the true misclassification cost per class in the `Cost` name-value pair when you run `ClassificationKNN.fit`. `Cost(i, j)` is the cost of classifying an observation into class `j` if its true class is `i`. By default, `Cost(i, j)=1` if `i~j`, and `Cost(i, j)=0` if `i=j`. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

Expected Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation. The third output of `predict` is the expected misclassification cost per observation.

Suppose you have `Nobs` observations that you want to classify with a trained classifier `mdl`. Suppose you have `K` classes. You place the observations into a matrix `Xnew` with one observation per row. The command

```
[label,score,cost] = predict(mdl,Xnew)
```

returns, among other outputs, a `cost` matrix of size `Nobs`-by-`K`. Each row of the `cost` matrix contains the expected (average) cost of classifying the observation into each of the `K` classes. `cost(n, k)` is

$$\sum_{i=1}^K \hat{P}(i | X_{new}(n)) C(k | i),$$

where

- K is the number of classes.
- $\hat{P}(i | X_{new}(n))$ is the posterior probability of class i for observation $X_{new}(n)$.
- $C(k | i)$ is the true misclassification cost of classifying an observation as k when its true class is i .

ClassificationKNN.resubLoss

Examples

Loss Calculation

Construct a k -nearest neighbor classifier for the Fisher iris data, where $k = 5$.

Load the data.

```
load fisheriris
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(meas,species,'NumNeighbors',5);
```

Examine the resubstitution loss of the classifier.

```
L = resubLoss(mdl)
```

```
L =
```

```
0.0333
```

The classifier predicts incorrect classifications for 1/30 of its training data.

See Also

[ClassificationKNN](#) | [resubEdge](#) | [resubMargin](#) | [resubPredict](#) |

Related Examples

- “Examine the Quality of a KNN Classifier” on page 13-26
- “Predict Classification Based on a KNN Classifier” on page 13-27
- “Modify a KNN Classifier” on page 13-27

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

Purpose

Classification error by resubstitution

Syntax

```
L = resubLoss(tree)
L = resubLoss(tree,Name,Value)
L = resubLoss(tree,'subtrees',subtreevector)
[L,se] = resubLoss(tree,'subtrees',subtreevector)
[L,se,NLeaf] = resubLoss(tree,'subtrees',subtreevector)
[L,se,NLeaf,bestlevel] = resubLoss(tree,'subtrees',
    subtreevector)
[L,...] =
resubLoss(tree,'subtrees',subtreevector,Name,Value)
```

Description

`L = resubLoss(tree)` returns the resubstitution loss, meaning the loss computed for the data that `ClassificationTree.fit` used to create `tree`.

`L = resubLoss(tree,Name,Value)` returns the loss with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ,NameN,ValueN`.

`L = resubLoss(tree,'subtrees',subtreevector)` returns a vector of classification errors for the trees in the pruning sequence `subtreevector`.

`[L,se] = resubLoss(tree,'subtrees',subtreevector)` returns the vector of standard errors of the classification errors.

`[L,se,NLeaf] = resubLoss(tree,'subtrees',subtreevector)` returns the vector of numbers of leaf nodes in the trees of the pruning sequence.

`[L,se,NLeaf,bestlevel] = resubLoss(tree,'subtrees',subtreevector)` returns the best pruning level as defined in the `treesize` name-value pair. By default, `bestlevel` is the pruning level that gives loss within one standard deviation of minimal loss.

`[L,...] = resubLoss(tree,'subtrees',subtreevector,Name,Value)` returns

ClassificationTree.resubLoss

loss statistics with additional options specified by one or more `Name, Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

Input Arguments

tree

A classification tree constructed by `ClassificationTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

lossfun

Function handle or string representing a loss function. Built-in loss functions:

- `'binodeviance'` — See “Loss Functions” on page 20-2134
- `'classiferror'` — Fraction of misclassified observations. See “Loss Functions” on page 20-2134.
- `'exponential'` — See “Loss Functions” on page 20-2134
- `'mincost'` — Smallest misclassification cost as given by the `tree.Cost` matrix. See “Loss Functions” on page 20-2134.

You can write your own loss function in the syntax described in “Loss Functions” on page 20-2134.

Default: `'mincost'`

`Name, Value` arguments associated with pruning subtrees:

subtrees

A vector with integer values from 0 (full unpruned tree) to the maximal pruning level `max(tree.PruneList)`.

Default: 0

treesize

One of the following strings:

- 'se' — `loss` returns the highest pruning level with loss within one standard deviation of the minimum ($L+se$, where L and se relate to the smallest value in subtrees).
- 'min' — `loss` returns the element of subtrees with smallest loss, usually the smallest element of subtrees.

Output Arguments

L

Classification error, a vector the length of subtrees. The meaning of the error depends on the values in `weights` and `lossfun`; see “Classification Error” on page 20-2134.

se

Standard error of loss, a vector the length of subtrees.

Nleaf

Number of leaves (terminal nodes) in the pruned subtrees, a vector the length of subtrees.

bestlevel

A scalar whose value depends on `treesize`:

- `treesize = 'se'` — `loss` returns the highest pruning level with loss within one standard deviation of the minimum ($L+se$, where L and se relate to the smallest value in subtrees).
- `treesize = 'min'` — `loss` returns the element of subtrees with smallest loss, usually the smallest element of subtrees.

ClassificationTree.resubLoss

Definitions

Classification Error

The default classification error is the fraction of the training data X that `tree` misclassifies.

Weighted classification error is the sum of weight i times the Boolean value that is 1 when `tree` misclassifies the i th row of X , divided by the sum of the weights.

Loss Functions

The built-in loss functions are:

- 'binodeviance' — For binary classification, assume the classes y_n are -1 and 1. With weight vector w normalized to have sum 1, and predictions of row n of data X as $f(X_n)$, the binomial deviance is

$$\sum w_n \log(1 + \exp(-2y_n f(X_n))).$$

- 'exponential' — With the same definitions as for 'binodeviance', the exponential loss is

$$\sum w_n \exp(-y_n f(X_n)).$$

- 'classiferror' — Predict the label with the largest posterior probability. The loss is then the fraction of misclassified observations.
- 'mincost' — Predict the label with the smallest expected misclassification cost, with expectation taken over the posterior probability, and cost as given by the `COST` property of the classifier (a matrix). The loss is then the true misclassification cost averaged over the observations.

To write your own loss function, create a function file in this form:

```
function loss = lossfun(C,S,W,COST)
```

- N is the number of rows of X .

- K is the number of classes in the classifier, represented in the `ClassNames` property.
- C is an N -by- K logical matrix, with one true per row for the true class. The index for each class is its position in the `ClassNames` property.
- S is an N -by- K numeric matrix. S is a matrix of posterior probabilities for classes with one row per observation, similar to the posterior output from `predict`.
- W is a numeric vector with N elements, the observation weights. If you pass W , the elements are normalized to sum to the prior probabilities in the respective classes.
- $COST$ is a K -by- K numeric matrix of misclassification costs. For example, you can use $COST = \text{ones}(K) - \text{eye}(K)$, which means a cost of 0 for correct classification, and 1 for misclassification.
- The output `loss` should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

True Misclassification Cost

There are two costs associated with classification: the true misclassification cost per class, and the expected misclassification cost per observation.

You can set the true misclassification cost per class in the `Cost` name-value pair when you create the classifier using the `ClassificationTree.fit` method. $Cost(i, j)$ is the cost of classifying an observation into class j if its true class is i . By default, $Cost(i, j) = 1$ if $i \neq j$, and $Cost(i, j) = 0$ if $i = j$. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

Expected Misclassification Cost

There are two costs associated with classification: the true misclassification cost per class, and the expected misclassification cost per observation.

ClassificationTree.resubLoss

Suppose you have `Nobs` observations that you want to classify with a trained classifier. Suppose you have `K` classes. You place the observations into a matrix `Xnew` with one observation per row.

The expected cost matrix `CE` has size `Nobs`-by-`K`. Each row of `CE` contains the expected (average) cost of classifying the observation into each of the `K` classes. `CE(n,k)` is

$$\sum_{i=1}^K \hat{P}(i | X_{new}(n)) C(k | i),$$

where

- `K` is the number of classes.
- $\hat{P}(i | X_{new}(n))$ is the posterior probability of class `i` for observation `Xnew(n)`.
- $C(k | i)$ is the true misclassification cost of classifying an observation as `k` when its true class is `i`.

Examples

Compute the resubstituted classification error for the ionosphere data:

```
load ionosphere
tree = ClassificationTree.fit(X,Y);
L = resubLoss(tree)
```

```
L =
    0.0114
```

See Also

`loss` | `resubEdge` | `resubMargin` | `resubPredict`

Purpose

Regression error by resubstitution

Syntax

```
L = resubLoss(ens)
L = resubLoss(ens,Name,Value)
```

Description

`L = resubLoss(ens)` returns the resubstitution loss, meaning the mean squared error computed for the data that `fitensemble` used to create `ens`.

`L = resubLoss(ens,Name,Value)` calculates loss with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

ens

A regression ensemble created with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

learners

Indices of weak learners in the ensemble ranging from 1 to `NTrained`. `resubLoss` uses only these learners for calculating loss.

Default: `1:NTrained`

lossfun

Function handle for loss function, or the string `'mse'`, meaning mean squared error. If you pass a function handle `fun`, `resubLoss` calls it as

```
FUN(Y,Yfit,W)
```

RegressionEnsemble.resubLoss

where Y , Y_{fit} , and W are numeric vectors of the same length. Y is the observed response, Y_{fit} is the predicted response, and W is the observation weights.

Default: 'mse'

mode

String representing the meaning of the output L :

- 'ensemble' — L is a scalar value, the loss for the entire ensemble.
- 'individual' — L is a vector with one element per trained learner.
- 'cumulative' — L is a vector in which element J is obtained by using learners $1:J$ from the input list of learners.

Default: 'ensemble'

Output Arguments

L

Loss, by default the mean squared error. L can be a vector, and can mean different things, depending on the name-value pair settings.

Examples

Find the resubstitution predictions of mileage from the `carsmall` data based on horsepower and weight, and look at their mean square difference from the training data.

```
load carsmall
X = [Horsepower Weight];
ens = fitensemble(X,MPG,'LSBoost',100,'Tree');
MSE = resubLoss(ens)
```

```
MSE =
    6.4336
```

See Also

[resubPredict](#) | [resubLoss](#) | [loss](#)

Purpose

Regression error by resubstitution

Syntax

```
L = resubLoss(tree)
L = resubLoss(tree,Name,Value)
L = resubLoss(tree,'subtrees',subtreevector)
[L,se] = resubLoss(tree,'subtrees',subtreevector)
[L,se,NLeaf] = resubLoss(tree,'subtrees',subtreevector)
[L,se,NLeaf,bestlevel] = resubLoss(tree,'subtrees',
    subtreevector)
[L,...] =
resubLoss(tree,'subtrees',subtreevector,Name,Value)
```

Description

`L = resubLoss(tree)` returns the resubstitution loss, meaning the loss computed for the data that `RegressionTree.fit` used to create `tree`.

`L = resubLoss(tree,Name,Value)` returns the loss with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ,NameN,ValueN`.

`L = resubLoss(tree,'subtrees',subtreevector)` returns a vector of mean squared errors for the trees in the pruning sequence `subtreevector`.

`[L,se] = resubLoss(tree,'subtrees',subtreevector)` returns the vector of standard errors of the classification errors.

`[L,se,NLeaf] = resubLoss(tree,'subtrees',subtreevector)` returns the vector of numbers of leaf nodes in the trees of the pruning sequence.

`[L,se,NLeaf,bestlevel] = resubLoss(tree,'subtrees',subtreevector)` returns the best pruning level as defined in the `treesize` name-value pair. By default, `bestlevel` is the pruning level that gives loss within one standard deviation of minimal loss.

`[L,...] = resubLoss(tree,'subtrees',subtreevector,Name,Value)` returns loss statistics with additional options specified by one or more

RegressionTree.resubLoss

Name, Value pair arguments. You can specify several name-value pair arguments in any order as Name1, Value1, ..., NameN, ValueN.

Input Arguments

tree

A regression tree constructed by RegressionTree.fit.

Name-Value Pair Arguments

Specify optional comma-separated pairs of Name, Value arguments, where Name is the argument name and Value is the corresponding value. Name must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as Name1, Value1, ..., NameN, ValueN.

lossfun

Function handle, or the string 'mse' meaning mean squared error.

You can write your own loss function in the syntax described in “Loss Functions” on page 20-2141.

Default: 'mse'

Name, Value arguments associated with pruning subtrees:

subtrees

A vector with integer values from 0 (full unpruned tree) to the maximal pruning level max(tree.PruneList).

Default: 0

treesize

One of the following strings:

- 'se' — `loss` returns the highest pruning level with loss within one standard deviation of the minimum ($L + se$, where L and se relate to the smallest value in subtrees).
- 'min' — `loss` returns the element of subtrees with smallest loss, usually the smallest element of subtrees.

Output Arguments

L

Mean squared error, a vector the length of subtrees. The meaning of the error depends on the values in `weights` and `lossfun`.

se

Standard error of loss, a vector the length of subtrees.

Nleaf

Number of leaves (terminal nodes) in the pruned subtrees, a vector the length of subtrees.

bestlevel

A scalar whose value depends on `treesize`:

- `treesize = 'se'` — `loss` returns the highest pruning level with loss within one standard deviation of the minimum ($L + se$, where L and se relate to the smallest value in subtrees).
- `treesize = 'min'` — `loss` returns the element of subtrees with smallest loss, usually the smallest element of subtrees.

Definitions

Loss Functions

The built-in loss function is 'mse', meaning mean squared error.

To write your own loss function, create a function file of the form

```
function loss = lossfun(Y,Yfit,W)
```

- N is the number of rows of `tree.X`.
- Y is an N -element vector representing the observed response.

RegressionTree.resubLoss

- Yfit is an N-element vector representing the predicted responses.
- W is an N-element vector representing the observation weights.
- The output loss should be a scalar.

Pass the function handle `@lossfun` as the value of the `lossfun` name-value pair.

Examples

Find the mean square error of a model of the `carsmall` data:

```
load carsmall
X = [Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
resubLoss(tree)
```

```
ans =
    4.8952
```

See Also

`resubPredict` | `loss`

ClassificationDiscriminant.resubMargin

Purpose	Classification margins by resubstitution
Syntax	<code>M = resubMargin(obj)</code>
Description	<code>M = resubMargin(obj)</code> returns resubstitution classification margins for <code>obj</code> .
Input Arguments	obj Discriminant analysis classifier, produced using <code>ClassificationDiscriminant.fit</code> .
Output Arguments	M Numeric column-vector of length <code>size(obj.X,1)</code> containing the classification margins.
Definitions	Margin The classification <i>margin</i> is the difference between the classification <i>score</i> for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix <code>obj.X</code> . A high value of margin indicates a more reliable prediction than a low value. Score (discriminant analysis) For discriminant analysis, the <i>score</i> of a classification is the posterior probability of the classification. For the definition of posterior probability in discriminant analysis, see “Posterior Probability” on page 12-7.
Examples	Find the margins for a classification tree for the Fisher iris data by resubstitution. Examine several entries: <pre>load fisheriris obj = ClassificationDiscriminant.fit(meas,species); M = resubMargin(obj); M(1:25:end)</pre>

ClassificationDiscriminant.resubMargin

```
ans =  
  1.0000  
  1.0000  
  0.9998  
  0.9998  
  1.0000  
  0.9946
```

See Also ClassificationDiscriminant | margin

How To • “Discriminant Analysis” on page 12-3

Purpose

Classification margins by resubstitution

Syntax

```
margin = resubMargin(ens)
margin = resubMargin(ens,Name,Value)
```

Description

`margin = resubMargin(ens)` returns the classification margin obtained by `ens` on its training data.

`margin = resubMargin(ens,Name,Value)` calculates margins with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A classification ensemble created with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

Indices of weak learners in the ensemble ranging from 1 to `NTrained`. `resubMargin` uses only these learners for calculating margin.

Default: `1:NTrained`

Output Arguments

margin

A numeric column-vector of length `size(ens.X,1)` containing the classification margins.

ClassificationEnsemble.resubMargin

Definitions

Margin

The classification *margin* is the difference between the classification *score* for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the matrix `ens.X`.

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

Examples

Find the resubstitution margins for an ensemble that classifies the Fisher iris data:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
margin = resubMargin(ens);
[min(margin) mean(margin) max(margin)]

ans =
    -0.5674     3.2486     4.6245
```

See Also

`resubEdge` | `resubLoss` | `resubPredict` | `resubMargin`

Purpose	Margin of k -nearest neighbor classifier by resubstitution
Syntax	<code>m = resubMargin mdl</code>
Description	<code>m = resubMargin mdl</code> returns the classification margins of the data used to train <code>mdl</code> . For the definition, see “Margin” on page 20-2147.
Input Arguments	mdl k -nearest neighbor classifier, created by <code>ClassificationKNN.fit</code> .
Output Arguments	m A numeric column vector of length <code>size mdl.X, 1</code> , where <code>mdl.X</code> is the training data for <code>mdl</code> . Each entry in <code>m</code> represents the margin for the corresponding row of <code>mdl.X</code> and (true class) <code>mdl.Y</code> .
Definitions	Margin The classification <i>margin</i> is the difference between the classification <i>score</i> for the true class and maximal classification score for the false classes. Margin is a column vector with the same number of rows as in the training data. Score The <i>score</i> of a classification is the posterior probability of the classification. The posterior probability is the number of neighbors that have that classification, divided by the number of neighbors. For a more detailed definition that includes weights and prior probabilities, see “Posterior Probability” on page 20-1830.
Examples	Resubstitution Margin Calculation Construct a k -nearest neighbor classifier for the Fisher iris data, where $k = 5$. Load the data.

ClassificationKNN.resubMargin

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',5);
```

Examine some statistics of the resubstitution margin of the classifier.

```
m = resubMargin(mdl);
[max(m) min(m) mean(m)]
```

```
ans =
```

```
1.0000 -0.6000 0.9253
```

The mean margin is over 0.9, indicating fairly high classification accuracy for resubstitution. For more reliable assessment of model accuracy, consider cross validation, such as `kfoldLoss`.

See Also

[ClassificationKNN](#) | [resubEdge](#) | [resubLoss](#) | [resubPredict](#) |

Related Examples

- “Examine the Quality of a KNN Classifier” on page 13-26

Concepts

- “Classification Using Nearest Neighbors” on page 13-9

Purpose	Classification margins by resubstitution
Syntax	<code>M = resubMargin(tree)</code>
Description	<code>M = resubMargin(tree)</code> returns resubstitution classification margins for <code>tree</code> .
Input Arguments	tree A classification tree created by <code>ClassificationTree.fit</code> .
Output Arguments	M A numeric column-vector of length <code>size(tree.X,1)</code> containing the classification margins.

Definitions

Margin

Classification *margin* is the difference between classification *score* for the true class and maximal classification score for the false classes. A high value of margin indicates a more reliable prediction than a low value.

Score (tree)

For trees, the *score* of a classification of a leaf node is the posterior probability of the classification at that node. The posterior probability of the classification at a node is the number of training sequences that lead to that node with the classification, divided by the number of training sequences that lead to that node.

For example, consider classifying a predictor X as true when $X < 0.15$ or $X > 0.95$, and X is false otherwise.

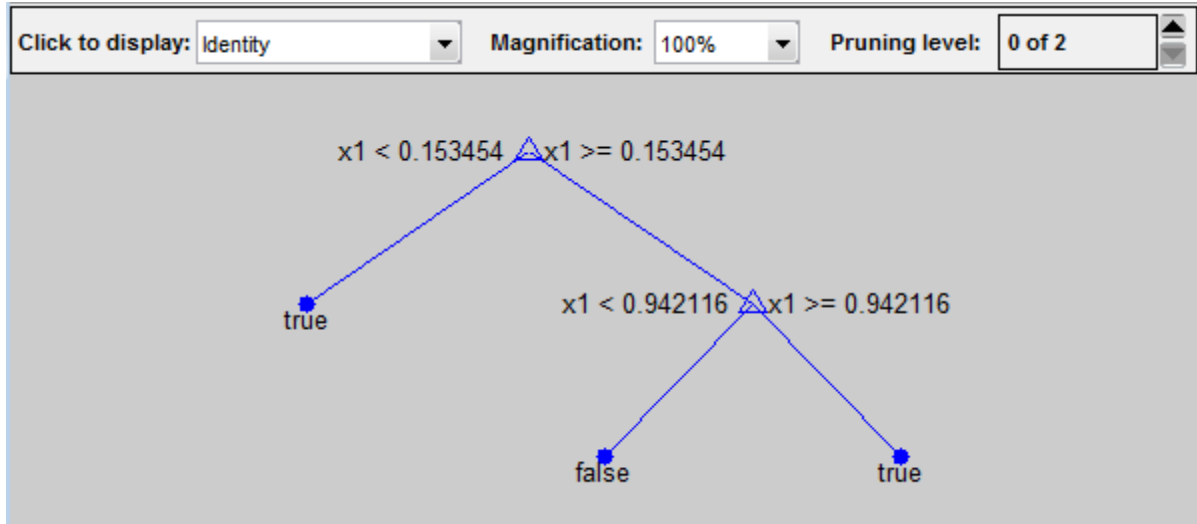
1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
```

ClassificationTree.resubMargin

```
Y = (abs(X - .55) > .4);  
tree = ClassificationTree.fit(X,Y);  
view(tree,'mode','graph')
```

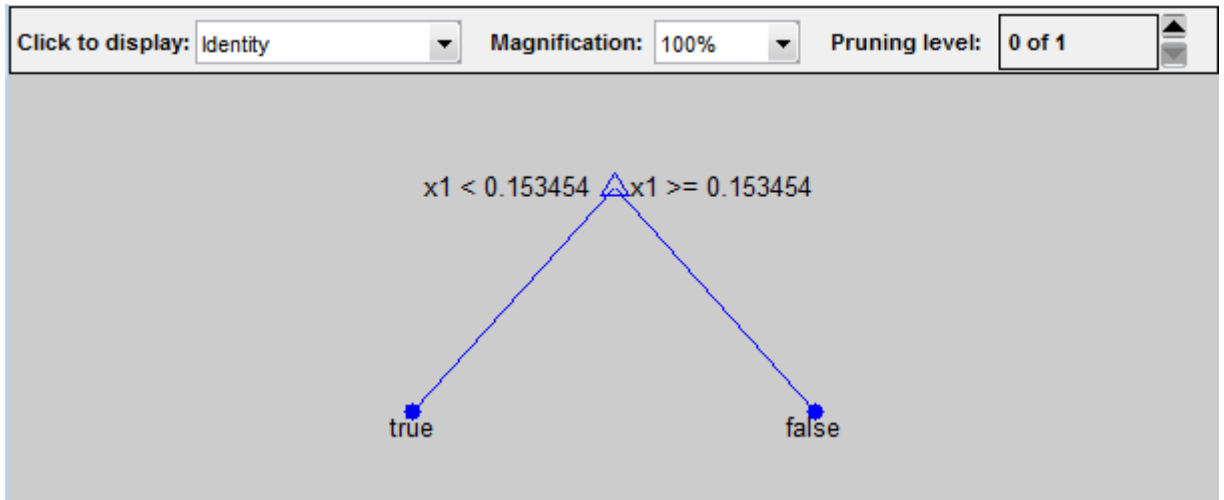


2

Prune the tree:

```
tree1 = prune(tree,'level',1);  
view(tree1,'mode','graph')
```


ClassificationTree.resubMargin



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations from .15 to .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore, the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));
[score X(1:10,:)]
```

```
ans =
    0.9059    0.0941    0.8147
    0.9059    0.0941    0.9058
         0     1.0000    0.1270
    0.9059    0.0941    0.9134
    0.9059    0.0941    0.6324
         0     1.0000    0.0975
    0.9059    0.0941    0.2785
```

ClassificationTree.resubMargin

```
0.9059    0.0941    0.5469
0.9059    0.0941    0.9575
0.9059    0.0941    0.9649
```

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.91 and 0.09. The difference (score 0.09 instead of the expected .06) is due to a statistical fluctuation: there are 8 observations in X in the range $(.95, 1)$ instead of the expected 5 observations.

Examples

Find the margins for a classification tree for the Fisher iris data by resubstitution. Examine several entries:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
M = resubMargin(tree);
M(1:25:end)

ans =
    1.0000
    1.0000
    1.0000
    1.0000
    0.9565
    0.9565
```

See Also

[margin](#) | [resubLoss](#) | [resubPredict](#) | [resubEdge](#)

Purpose	Predict resubstitution response of classifier
Syntax	<pre>label = resubPredict(obj) [label,posterior] = resubPredict(obj) [label,posterior,cost] = resubPredict(obj)</pre>
Description	<p>label = resubPredict(obj) returns the labels obj predicts for the data obj.X. label is the predictions of obj on the data that ClassificationDiscriminant.fit used to create obj.</p> <p>[label,posterior] = resubPredict(obj) returns the posterior class probabilities for the predictions.</p> <p>[label,posterior,cost] = resubPredict(obj) returns the predicted misclassification costs per class for the resubstituted data.</p>
Input Arguments	<p>obj</p> <p>Discriminant analysis classifier, produced using ClassificationDiscriminant.fit.</p>
Output Arguments	<p>label</p> <p>Response obj predicts for the training data. label is the same data type as the training response data obj.Y. The predicted class labels are those with minimal expected misclassification cost; see “How the predict Method Classifies” on page 12-6.</p> <p>posterior</p> <p>N-by-K matrix of posterior probabilities for classes obj predicts, where N is the number of observations and K is the number of classes.</p> <p>cost</p> <p>N-by-K matrix of predicted misclassification costs. Each cost is the average misclassification cost with respect to the posterior probability.</p>

ClassificationDiscriminant.resubPredict

Definitions

Posterior Probability

`posterior(i,k)` is the posterior probability of class `k` for observation `i`. For the mathematical definition, see “Posterior Probability” on page 12-7.

Examples

Find the total number of misclassifications of the Fisher iris data for a discriminant analysis classifier:

```
load fisheriris
obj = ClassificationDiscriminant.fit(meas,species);
Ypredict = resubPredict(obj); % the predictions
Ysame = strcmp(Ypredict,species); % true when ==
sum(~Ysame) % how many are different?

ans =
     3
```

See Also

`ClassificationDiscriminant` | `predict`

How To

- “Discriminant Analysis” on page 12-3

Purpose

Predict ensemble response by resubstitution

Syntax

```
label = resubPredict(ens)
[label,score] = resubPredict(ens)
[label,score] = resubPredict(ens,Name,Value)
```

Description

`label = resubPredict(ens)` returns the labels `ens` predicts for the data `ens.X`. `label` is the predictions of `ens` on the data that `fitensemble` used to create `ens`.

`[label,score] = resubPredict(ens)` also returns scores for all classes.

`[label,score] = resubPredict(ens,Name,Value)` finds resubstitution predictions with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A classification ensemble created with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

learners

Indices of weak learners in the ensemble ranging from 1 to `NTrained`. `oobLoss` uses only these learners for calculating loss.

Default: 1:`NTrained`

ClassificationEnsemble.resubPredict

Output Arguments

label

The response `ens` predicts for the training data. `label` is the same data type as the training response data `ens.Y`, and has the same number of entries as the number of rows in `ens.X`.

score

An N-by-K matrix, where N is the number of rows in `ens.X`, and K is the number of classes in `ens`. High score value indicates that an observation likely comes from this class.

Definitions

Score (ensemble)

For ensembles, a classification *score* represents the confidence of a classification into a class. The higher the score, the higher the confidence.

Different ensemble algorithms have different definitions for their scores. Furthermore, the range of scores depends on ensemble type. For example:

- AdaBoostM1 scores range from $-\infty$ to ∞ .
- Bag scores range from 0 to 1.

Examples

Find the total number of misclassifications of the Fisher iris data for a classification ensemble:

```
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,'Tree');
Ypredict = resubPredict(ens); % the predictions
Ysame = strcmp(Ypredict,species); % true when ==
sum(~Ysame) % how many are different?

ans =
    5
```

See Also

[resubEdge](#) | [resubMargin](#) | [resubLoss](#) | [resubPredict](#)

Purpose	Predict resubstitution response of k -nearest neighbor classifier
Syntax	<pre>label = resubPredict mdl [label,score] = resubPredict mdl [label,score,cost] = resubPredict mdl</pre>
Description	<p>label = resubPredict mdl returns the labels mdl predicts for the data mdl.X. label is the predictions of mdl on the data that ClassificationKNN.fit used to create mdl.</p> <p>[label,score] = resubPredict mdl returns the posterior class probabilities for the predictions.</p> <p>[label,score,cost] = resubPredict mdl returns the misclassification costs.</p>
Input Arguments	<p>mdl</p> <p>k-nearest neighbor classifier, created by ClassificationKNN.fit.</p>
Output Arguments	<p>label</p> <p>Predicted class labels for the points in the training data X, a vector with length equal to the number of rows in the training data X. The label is the class with minimal expected cost (see “Expected Cost” on page 20-2158).</p> <p>score</p> <p>Numeric matrix of size N-by-K, where N is the number of observations (rows) in the training data X, and K is the number of classes (in mdl.ClassNames). score(i,j) is the posterior probability that row i of X is of class j. See “Posterior Probability” on page 20-2158.</p> <p>cost</p> <p>Matrix of expected costs of size N-by-K, where N is the number of observations (rows) in the training data X, and K is the number of</p>

ClassificationKNN.resubPredict

classes (in `mdl.ClassNames`). `cost(i, j)` is the cost of classifying row `i` of `X` as class `j`. See “Expected Cost” on page 20-2158.

Definitions Posterior Probability

For a vector (single query point) `X` and model `mdl`, let

- `K` be the number of nearest neighbors used in prediction, `mdl.NumNeighbors`
- `nbd(mdl, X)` be the `K` nearest neighbors to `X` in `mdl.X`
- `Y(nbd)` be the classifications of the points in `nbd(mdl, X)`, namely `mdl.Y(nbd)`
- `W(nbd)` be the weights of the points in `nbd(mdl, X)`
- `prior` be the priors of the classes in `mdl.Y`

If there is a vector of prior probabilities, then the observation weights `W` are normalized by class to sum to the priors. This might involve a calculation for the point `X`, because weights can depend on the distance from `X` to the points in `mdl.X`.

The posterior probability $p(j | X)$ is

$$p(j | X) = \frac{\sum_{i \in \text{nbd}} W(i) 1_{Y(X(i)=j)}}{\sum_{i \in \text{nbd}} W(i)}.$$

Here $1_{Y(X(i)=j)}$ means 1 when `mdl.Y(i) = j`, and 0 otherwise.

Expected Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation. The third output of `predict` is the expected misclassification cost per observation.

Suppose you have `Nobs` observations that you want to classify with a trained classifier `mdl`. Suppose you have `K` classes. You place the observations into a matrix `X` with one observation per row. The command

```
[label,score,cost] = predict(mdl,X)
```

returns, among other outputs, a `cost` matrix of size `Nobs`-by-`K`. Each row of the `cost` matrix contains the expected (average) cost of classifying the observation into each of the `K` classes. `cost(n,k)` is

$$\sum_{i=1}^K \hat{P}(i | X(n)) C(k | i),$$

where

- K is the number of classes.
- $\hat{P}(i | X(n))$ is the posterior probability of class i for observation $X(n)$.
- $C(k | i)$ is the true misclassification cost of classifying an observation as k when its true class is i .

True Misclassification Cost

There are two costs associated with KNN classification: the true misclassification cost per class, and the expected misclassification cost per observation.

You can set the true misclassification cost per class in the `Cost` name-value pair when you run `ClassificationKNN.fit`. `Cost(i,j)` is the cost of classifying an observation into class j if its true class is i . By default, `Cost(i,j)=1` if $i \neq j$, and `Cost(i,j)=0` if $i=j$. In other words, the cost is 0 for correct classification, and 1 for incorrect classification.

Examples

Resubstitution Prediction

Examine the quality of a classifier by its resubstitution predictions.

ClassificationKNN.resubPredict

Load the data.

```
load fisheriris
X = meas;
Y = species;
```

Construct a classifier for 5-nearest neighbors.

```
mdl = ClassificationKNN.fit(X,Y,'NumNeighbors',5);
```

Generate the resubstitution predictions.

```
label = resubPredict(mdl);
```

Calculate the number of differences between the predictions label and the original data Y.

```
mydiff = not(strcmp(Y,label)); % mydiff(i) = 1 means they differ
sum(mydiff) % number of differences

ans =
     5
```

See Also

[ClassificationKNN](#) | [predict](#) | [resubEdge](#) | [resubLoss](#) | [resubMargin](#) |

Purpose Predict resubstitution response of tree

Syntax

```
label = resubPredict(tree)
[label,posterior] = resubPredict(tree)
[label,posterior,node] = resubPredict(tree)
[label,posterior,node,cnum] = resubPredict(tree)
[label,...] = resubPredict(tree,Name,Value)
```

Description

`label = resubPredict(tree)` returns the labels tree predicts for the data `tree.X`. `label` is the predictions of tree on the data that `ClassificationTree.fit` used to create tree.

`[label,posterior] = resubPredict(tree)` returns the posterior class probabilities for the predictions.

`[label,posterior,node] = resubPredict(tree)` returns the node numbers of tree for the resubstituted data.

`[label,posterior,node,cnum] = resubPredict(tree)` returns the predicted class numbers for the predictions.

`[label,...] = resubPredict(tree,Name,Value)` returns resubstitution predictions with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

tree

A classification tree constructed by `ClassificationTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

subtrees

ClassificationTree.resubPredict

A vector with integer values from 0 (full unpruned tree) to the maximal pruning level `max(tree.PruneList)`. `subtrees` must be in ascending order.

Default: 0

Output Arguments

label

The response `tree` predicts for the training data. `label` is the same data type as the training response data `tree.Y`.

If the `subtrees` name-value argument contains $m > 1$ entries, `label` has m columns, each of which represents the predictions of the corresponding subtree. Otherwise, `label` is a vector.

posterior

Matrix or array of posterior probabilities for classes `tree` predicts.

If the `subtrees` name-value argument is a scalar or is missing, `posterior` is an n -by- k matrix, where n is the number of rows in the training data `tree.X`, and k is the number of classes.

If `subtrees` contains $m > 1$ entries, `posterior` is an n -by- k -by- m array, where the matrix for each m gives posterior probabilities for the corresponding subtree.

node

The node numbers of `tree` where each data row resolves.

If the `subtrees` name-value argument is a scalar or is missing, `node` is a numeric column vector with n rows, the same number of rows as `tree.X`.

If `subtrees` contains $m > 1$ entries, `node` is a n -by- m matrix. Each column represents the node predictions of the corresponding subtree.

cnum

The class numbers that `tree` predicts for the resubstituted data.

If the `subtrees` name-value argument is a scalar or is missing, `cnum` is a numeric column vector with `n` rows, the same number of rows as `tree.X`.

If `subtrees` contains `m>1` entries, `cnum` is a `n`-by-`m` matrix. Each column represents the class predictions of the corresponding subtree.

Definitions

Posterior Probability

The posterior probability of the classification at a node is the number of training sequences that lead to that node with this classification, divided by the number of training sequences that lead to that node.

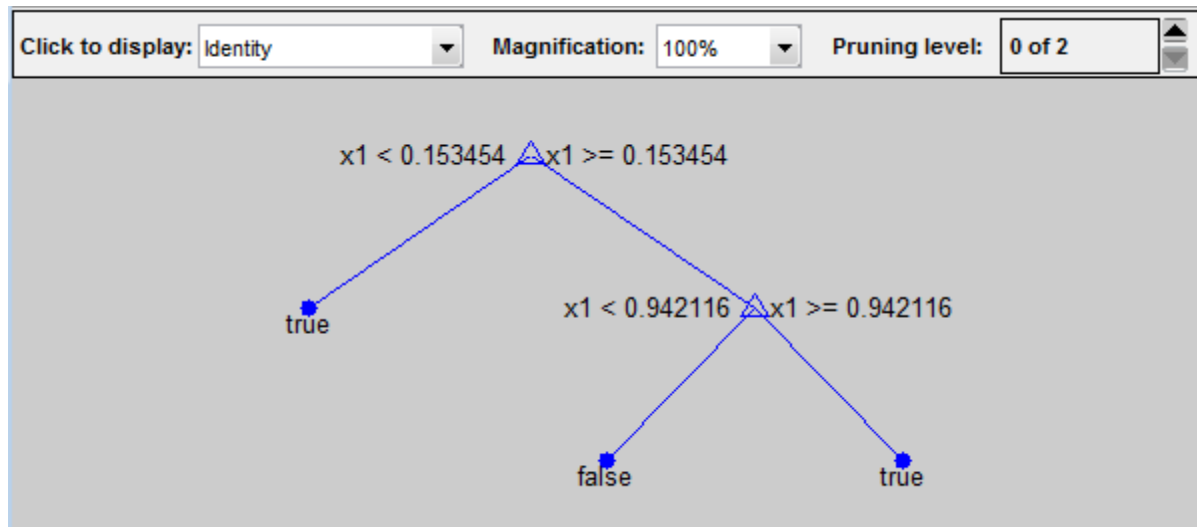
For example, consider classifying a predictor `X` as `true` when `X<0.15` or `X>0.95`, and `X` is `false` otherwise.

1

Generate 100 random points and classify them:

```
rng(0,'twister') % for reproducibility
X = rand(100,1);
Y = (abs(X - .55) > .4);
tree = ClassificationTree.fit(X,Y);
view(tree,'mode','graph')
```

ClassificationTree.resubPredict

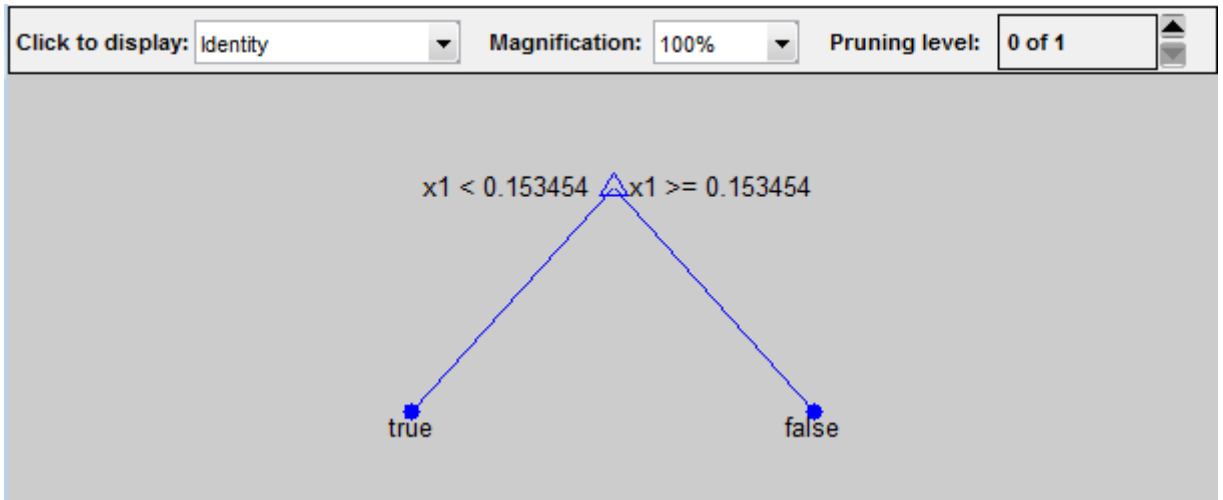


2

Prune the tree:

```
tree1 = prune(tree, 'level', 1);  
view(tree1, 'mode', 'graph')
```

ClassificationTree.resubPredict



The pruned tree correctly classifies observations that are less than 0.15 as true. It also correctly classifies observations between .15 and .94 as false. However, it incorrectly classifies observations that are greater than .94 as false. Therefore the score for observations that are greater than .15 should be about $.05/.85=.06$ for true, and about $.8/.85=.94$ for false.

3

Compute the prediction scores for the first 10 rows of X:

```
[~,score] = predict(tree1,X(1:10));
[score X(1:10,:)]
```

```
ans =
    0.9405    0.0595    0.6555
    0.9405    0.0595    0.1712
    0.9405    0.0595    0.7060
         0    1.0000    0.0318
    0.9405    0.0595    0.2769
         0    1.0000    0.0462
```

ClassificationTree.resubPredict

	0	1.0000	0.0971
	0.9405	0.0595	0.8235
	0.9405	0.0595	0.6948
	0.9405	0.0595	0.3171

Indeed, every value of X (the rightmost column) that is less than 0.15 has associated scores (the left and center columns) of 0 and 1, while the other values of X have associated scores of 0.94 and 0.06.

Examples

Find the total number of misclassifications of the Fisher iris data for a classification tree:

```
load fisheriris
tree = ClassificationTree.fit(meas,species);
Ypredict = resubPredict(tree); % the predictions
Ysame = strcmp(Ypredict,species); % true when ==
sum(~Ysame) % how many are different?
```

```
ans =
     3
```

See Also

[resubEdge](#) | [resubMargin](#) | [resubLoss](#) | [predict](#)

Purpose	Predict response of ensemble by resubstitution
Syntax	<pre>Yfit = resubPredict(ens) Yfit = resubPredict(ens,Name,Value)</pre>
Description	<p><code>Yfit = resubPredict(ens)</code> returns the response <code>ens</code> predicts for the data <code>ens.X</code>. <code>Yfit</code> is the predictions of <code>ens</code> on the data that <code>fitensemble</code> used to create <code>ens</code>.</p> <p><code>Yfit = resubPredict(ens,Name,Value)</code> predicts responses with additional options specified by one or more <code>Name,Value</code> pair arguments.</p>
Input Arguments	<p>ens</p> <p>A regression ensemble created with <code>fitensemble</code>.</p> <p>Name-Value Pair Arguments</p> <p>Specify optional comma-separated pairs of <code>Name,Value</code> arguments, where <code>Name</code> is the argument name and <code>Value</code> is the corresponding value. <code>Name</code> must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as <code>Name1,Value1,...,NameN,ValueN</code>.</p> <p>learners</p> <p>Indices of weak learners in the ensemble ranging from 1 to <code>NTrained</code>. <code>oobLoss</code> uses only these learners for calculating loss.</p> <p>Default: <code>1:NTrained</code></p>
Output Arguments	<p>Yfit</p> <p>A vector of predicted responses to the training data, with <code>ens.X</code> elements.</p>

RegressionEnsemble.resubPredict

Examples

Find the resubstitution predictions of mileage from the `carsmall` data based on horsepower and weight, and look at their mean square difference from the training data.

```
load carsmall
X = [Horsepower Weight];
ens = fitensemble(X,MPG,'LSBoost',100,'Tree');
Yfit = resubPredict(ens);
MSE = mean((Yfit - ens.Y).^2)
```

```
MSE =
    6.4336
```

This is the same as the result of `resubLoss`:

```
resubLoss(ens)

ans =
    6.4336
```

See Also

[resubLoss](#) | [resubPredict](#) | [predict](#)

Purpose

Predict resubstitution response of tree

Syntax

```
Yfit = resubPredict(tree)
[Yfit,node] = resubPredict(tree)
[Yfit,node] = resubPredict(tree,Name,Value)
```

Description

`Yfit = resubPredict(tree)` returns the responses tree predicts for the data `tree.X`. `Yfit` is the predictions of tree on the data that `RegressionTree.fit` used to create tree.

`[Yfit,node] = resubPredict(tree)` returns the node numbers of tree for the resubstituted data.

`[Yfit,node] = resubPredict(tree,Name,Value)` predicts with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

tree

A regression tree constructed by `RegressionTree.fit`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

subtrees

A vector with integer values from 0 (full unpruned tree) to the maximal pruning level `max(tree.PruneList)`. `subtrees` must be in ascending order.

Default: 0

Output Arguments

Yfit

The response tree predicts for the training data.

RegressionTree.resubPredict

If the `subtrees` name-value argument is a scalar or is missing, `label` is the same data type as the training response data `tree.Y`.

If `subtrees` contains $m > 1$ entries, `label` has m columns, each of which represents the predictions of the corresponding subtree.

node

The tree node numbers where `tree` sends each data row.

If the `subtrees` name-value argument is a scalar or is missing, `node` is a numeric column vector with n rows, the same number of rows as `tree.X`.

If `subtrees` contains $m > 1$ entries, `node` is a n -by- m matrix. Each column represents the node predictions of the corresponding subtree.

Examples

Find the mean square error of a model of the `carsmall` data:

```
load carsmall
X = [Displacement Horsepower Weight];
tree = RegressionTree.fit(X,MPG);
Yfit = resubPredict(tree);
mean((Yfit - tree.Y).^2)
```

```
ans =
    4.8952
```

You can get the same answer using `resubLoss`:

```
resubLoss(tree)

ans =
    4.8952
```

See Also

[resubLoss](#) | [predict](#)

Purpose Resume training ensemble

Syntax
`ens1 = resume(ens,nlearn)`
`ens1 = resume(ens,nlearn,Name,Value)`

Description `ens1 = resume(ens,nlearn)` trains `ens` for `nlearn` more cycles. `resume` uses the same training options `fitensemble` used to create `ens`.

Note You cannot resume training when `ens` is a Subspace ensemble created with 'AllPredictorCombinations' number of learners.

`ens1 = resume(ens,nlearn,Name,Value)` trains `ens` with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A classification ensemble, created with `fitensemble`.

nlearn

A positive integer, the number of cycles for additional training of `ens`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

nprint

Printout frequency, a positive integer scalar or 'off' (no printouts). Returns to the command line the number of weak learners trained so far. Useful when you train ensembles with many learners on large data sets.

ClassificationEnsemble.resume

Default: 'off'

Output Arguments

ens1

The classification ensemble `ens`, augmented with additional training.

Examples

Train a classification ensemble for 10 cycles. Examine the resubstitution error. Then train for 10 more cycles and examine the new resubstitution error.

```
load ionosphere
ens = fitensemble(X,Y,'GentleBoost',10,'Tree');
L = resubLoss(ens)
```

```
L =
    0.0484
```

```
ens1 = resume(ens,10);
L = resubLoss(ens1)
```

```
L =
    0.0256
```

The new ensemble has much less resubstitution error than the original.

See Also

`fitensemble`

Purpose

Resume training learners on cross-validation folds

Syntax

```
ens1 = resume(ens,nlearn)
ens1 = resume(ens,nlearn,Name,Value)
```

Description

`ens1 = resume(ens,nlearn)` trains `ens` in every fold for `nlearn` more cycles. `resume` uses the same training options `fitensemble` used to create `ens`.

`ens1 = resume(ens,nlearn,Name,Value)` trains `ens` with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A cross-validated classification ensemble. `ens` is the result of either:

- The `fitensemble` function with a cross-validation name-value pair. The names are `'crossval'`, `'kfold'`, `'holdout'`, `'leaveout'`, or `'cvpartition'`.
- The `crossval` method applied to a classification ensemble.

nlearn

A positive integer, the number of cycles for additional training of `ens`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

nprint

Printout frequency, a positive integer scalar or `'off'` (no printouts). Returns to the command line the number of weak

ClassificationPartitionedEnsemble.resume

learners trained so far. Useful when you train ensembles with many learners on large data sets.

Default: 'off'

Output Arguments

ens1

The cross-validated classification ensemble `ens`, augmented with additional training.

Examples

Train a partitioned classification ensemble for 10 cycles. Examine the error. Then train for 10 more cycles and examine the new error.

```
load ionosphere
cvens = fitensemble(X,Y,'GentleBoost',10,'Tree',...
    'crossval','on');
L = kfoldLoss(cvens)
```

```
L =
    0.0883
```

```
cvens = resume(cvens,10);
L = kfoldLoss(cvens)
```

```
L =
    0.0769
```

The ensemble has less cross-validation error after training for ten more cycles.

See Also

[kfoldPredict](#) | [kfoldEdge](#) | [kfoldMargin](#) | [kfoldLoss](#)

Purpose Resume training ensemble

Syntax
`ens1 = resume(ens,nlearn)`
`ens1 = resume(ens,nlearn,Name,Value)`

Description
`ens1 = resume(ens,nlearn)` trains `ens` for `nlearn` more cycles.
`resume` uses the same training options `fitensemble` used to create `ens`.
`ens1 = resume(ens,nlearn,Name,Value)` trains `ens` with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A regression ensemble, created with `fitensemble`.

nlearn

A positive integer, the number of cycles for additional training of `ens`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

nprint

Printout frequency, a positive integer scalar or 'off' (no printouts). Returns to the command line the number of weak learners trained so far. Useful when you train ensembles with many learners on large data sets.

Default: 'off'

RegressionEnsemble.resume

Output Arguments

ens1

The regression ensemble `ens`, augmented with additional training.

Examples

Train a regression ensemble for 50 cycles. Examine the resubstitution error. Then train for 50 more cycles and examine the new resubstitution error.

```
load carsmall
X = [Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'LSBoost',50,'Tree');
L = resubLoss(ens)
```

```
L =
    6.2681
```

```
ens = resume(ens,50);
L = resubLoss(ens)
```

```
L =
    4.3904
```

The new ensemble has much less resubstitution error than the original.

See Also

`fitensemble`

RegressionPartitionedEnsemble.resume

Purpose

Resume training ensemble

Syntax

```
ens1 = resume(ens,nlearn)
ens1 = resume(ens,nlearn,Name,Value)
```

Description

`ens1 = resume(ens,nlearn)` trains `ens` in every fold for `nlearn` more cycles. `resume` uses the same training options `fitensemble` used to create `ens`.

`ens1 = resume(ens,nlearn,Name,Value)` trains `ens` with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

ens

A cross-validated regression ensemble. `ens` is the result of either:

- The `fitensemble` function with a cross-validation name-value pair. The names are 'crossval', 'kfold', 'holdout', 'leaveout', or 'cvpartition'.
- The `crossval` method applied to a regression ensemble.

nlearn

A positive integer, the number of cycles for additional training of `ens`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

nprint

Printout frequency, a positive integer scalar or 'off' (no printouts). Returns to the command line the number of weak

RegressionPartitionedEnsemble.resume

learners trained so far. Useful when you train ensembles with many learners on large data sets.

Default: 'off'

Output Arguments

ens1

The cross-validated regression ensemble `ens`, augmented with additional training.

Examples

Train a regression ensemble for 50 cycles, and cross validate it. Examine the cross-validation error. Then train for 50 more cycles and examine the new cross-validation error.

```
load carsmall
X = [Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'LSBoost',50,'Tree');
cvens = crossval(ens);
L = kfoldLoss(cvens)
```

```
L =
    25.6573
```

```
cvens = resume(cvens,50);
L = kfoldLoss(cvens)
```

```
L =
    26.7563
```

The additional training did not improve the cross-validation error.

See Also

`fitensemble` | `kfoldLoss`

Purpose

Ridge regression

Syntax

```
b = ridge(y,X,k)
b = ridge(y,X,k,scaled)
```

Description

`b = ridge(y,X,k)` returns a vector `b` of coefficient estimates for a multilinear ridge regression of the responses in `y` on the predictors in `X`. `X` is an n -by- p matrix of p predictors at each of n observations. `y` is an n -by-1 vector of observed responses. `k` is a vector of ridge parameters. If `k` has m elements, `b` is p -by- m . By default, `b` is computed after centering and scaling the predictors to have mean 0 and standard deviation 1. The model does not include a constant term, and `X` should not contain a column of 1s.

`b = ridge(y,X,k,scaled)` uses the `{0,1}`-valued flag `scaled` to determine if the coefficient estimates in `b` are restored to the scale of the original data. `ridge(y,X,k,0)` performs this additional transformation. In this case, `b` contains $p+1$ coefficients for each value of `k`, with the first row corresponding to a constant term in the model. `ridge(y,X,k,1)` is the same as `ridge(y,X,k)`. In this case, `b` contains p coefficients, without a coefficient for a constant term.

The relationship between `b0 = ridge(y,X,k,0)` and `b1 = ridge(y,X,k,1)` is given by

```
m = mean(X);
s = std(X,0,1)';
b1_scaled = b1./s;
b0 = [mean(y)-m*b1_scaled; b1_scaled]
```

This can be seen by replacing the x_i ($i = 1, \dots, n$) in the multilinear model $y = b_0^0 + b_1^0 x_1 + \dots + b_n^0 x_n$ with the z -scores $z_i = (x_i - \mu_i)/\sigma_i$, and replacing y with $y - \mu_y$.

In general, `b1` is more useful for producing plots in which the coefficients are to be displayed on the same scale, such as a *ridge trace* (a plot of the regression coefficients as a function of the ridge parameter). `b0` is more useful for making predictions.

Coefficient estimates for multiple linear regression models rely on the independence of the model terms. When terms are correlated and the columns of the design matrix X have an approximate linear dependence, the matrix $(X^T X)^{-1}$ becomes close to singular. As a result, the least-squares estimate

$$\hat{\beta} = (X^T X)^{-1} X^T y$$

becomes highly sensitive to random errors in the observed response y , producing a large variance. This situation of *multicollinearity* can arise, for example, when data are collected without an experimental design.

Ridge regression addresses the problem by estimating regression coefficients using

$$\hat{\beta} = (X^T X + kI)^{-1} X^T y$$

where k is the *ridge parameter* and I is the identity matrix. Small positive values of k improve the conditioning of the problem and reduce the variance of the estimates. While biased, the reduced variance of ridge estimates often result in a smaller mean square error when compared to least-squares estimates.

Examples

Load the data in `acetylene.mat`, with observations of the predictor variables `x1`, `x2`, `x3`, and the response variable `y`:

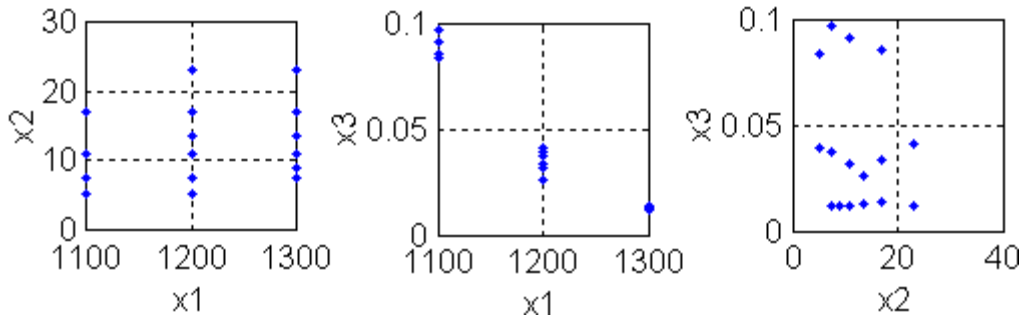
```
load acetylene
```

Plot the predictor variables against each other:

```
subplot(1,3,1)
plot(x1,x2, '.')
xlabel('x1'); ylabel('x2'); grid on; axis square
```

```
subplot(1,3,2)
plot(x1,x3, '.')
xlabel('x1'); ylabel('x3'); grid on; axis square
```

```
subplot(1,3,3)
plot(x2,x3,'.')
xlabel('x2'); ylabel('x3'); grid on; axis square
```



Note the correlation between x_1 and the other two predictor variables.

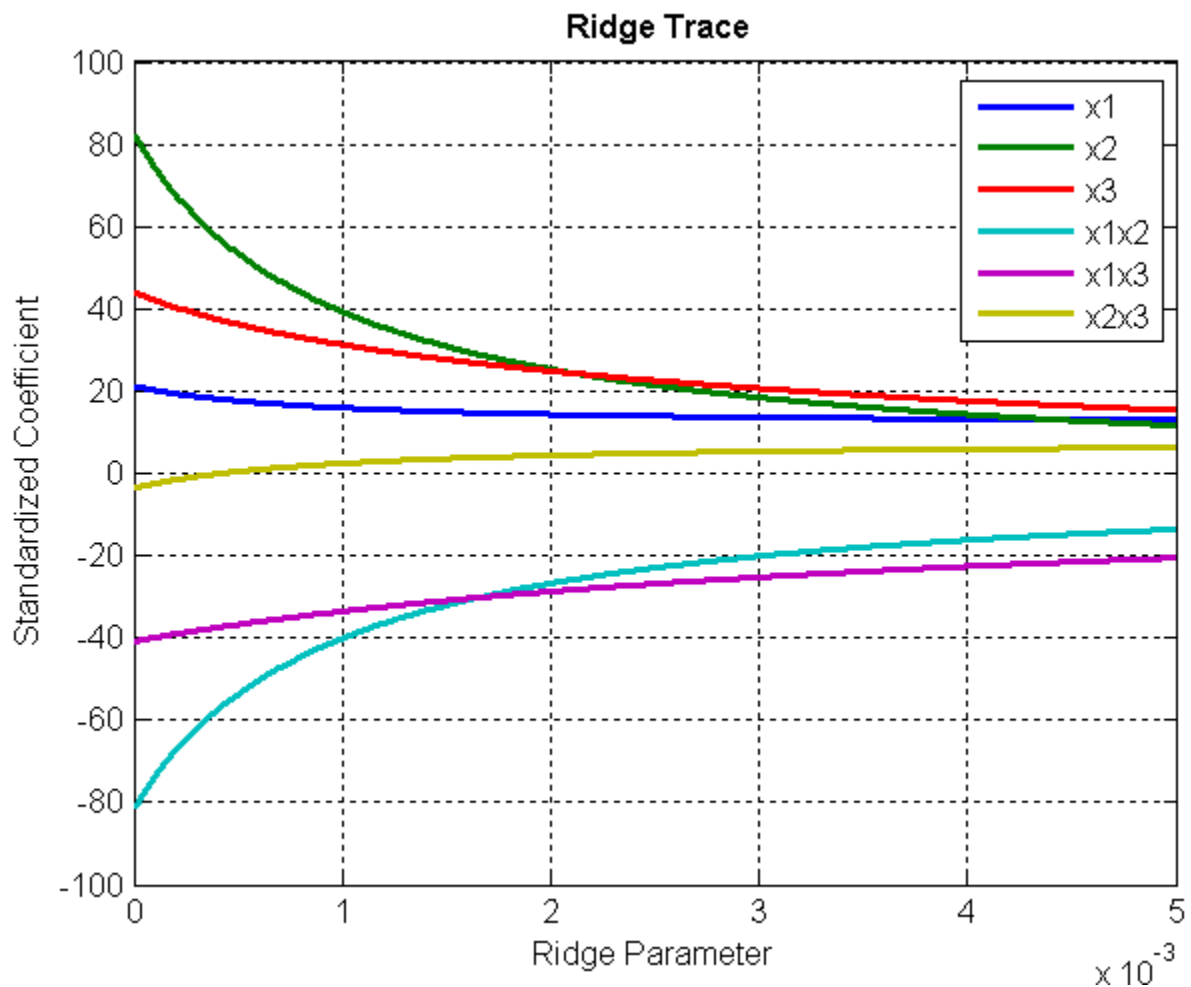
Use `ridge` and `x2fx` to compute coefficient estimates for a multilinear model with interaction terms, for a range of ridge parameters:

```
X = [x1 x2 x3];
D = x2fx(X,'interaction');
D(:,1) = []; % No constant term
k = 0:1e-5:5e-3;
b = ridge(y,D,k);
```

Plot the ridge trace:

```
figure
plot(k,b,'LineWidth',2)
ylim([-100 100])
grid on
xlabel('Ridge Parameter')
ylabel('Standardized Coefficient')
title('\bf Ridge Trace')
legend('x1','x2','x3','x1x2','x1x3','x2x3')
```

ridge



The estimates stabilize to the right of the plot. Note that the coefficient of the x_2x_3 interaction term changes sign at a value of the ridge parameter $\approx 5 \times 10^{-4}$.

References

- [1] Hoerl, A. E., and R. W. Kennard. "Ridge Regression: Biased Estimation for Nonorthogonal Problems." *Technometrics*. Vol. 12, No. 1, 1970, pp. 55–67.
- [2] Hoerl, A. E., and R. W. Kennard. "Ridge Regression: Applications to Nonorthogonal Problems." *Technometrics*. Vol. 12, No. 1, 1970, pp. 69–82.
- [3] Marquardt, D.W. "Generalized Inverses, Ridge Regression, Biased Linear Estimation, and Nonlinear Estimation." *Technometrics*. Vol. 12, No. 3, 1970, pp. 591–612.
- [4] Marquardt, D. W., and R.D. Snee. "Ridge Regression in Practice." *The American Statistician*. Vol. 29, No. 1, 1975, pp. 3–20.

See Also

regress | stepwise

classregtree.risk

Purpose Node risks

Syntax `r = risk(t)`
`r = risk(t,nodes)`

Description `r = risk(t)` returns an n -element vector r of the risk of the nodes in the tree t , where n is the number of nodes. The risk $r(i)$ for node i is the node error $e(i)$ (computed by `nodeerr`) weighted by the node probability $p(i)$ (computed by `nodeprob`).

`r = risk(t,nodes)` takes a vector `nodes` of node numbers and returns the risk values for the specified nodes.

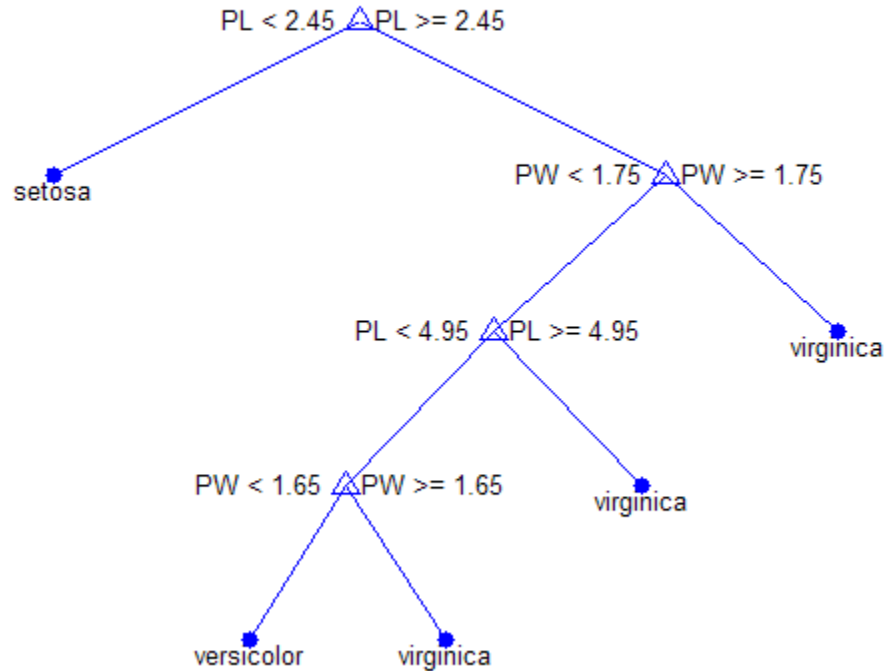
Examples Create a classification tree for Fisher's iris data:

```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

Click to display: Magnification: Pruning level:



```

e = nodeerr(t);
p = nodeprob(t);
r = risk(t);

```

```

r
r =
    0.6667
         0
    0.3333
    0.0333

```

classregtree.risk

```
0.0067
0.0067
0.0133
0
0

e.*p
ans =
0.6667
0
0.3333
0.0333
0.0067
0.0067
0.0133
0
0
```

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree | nodeerr | nodeprob

Purpose Interactive robust regression

Syntax `robustdemo`
`robustdemo(x,y)`

Description `robustdemo` shows the difference between ordinary least squares and robust regression for data with a single predictor. With no input arguments, `robustdemo` displays a scatter plot of a sample of roughly linear data with one outlier. The bottom of the figure displays equations of lines fitted to the data using ordinary least squares and robust methods, together with estimates of the root mean squared errors.

Use the right mouse button to click on a point and view its least-squares leverage and robust weight.

Use the left mouse button to click-and-drag a point. The displays will update.

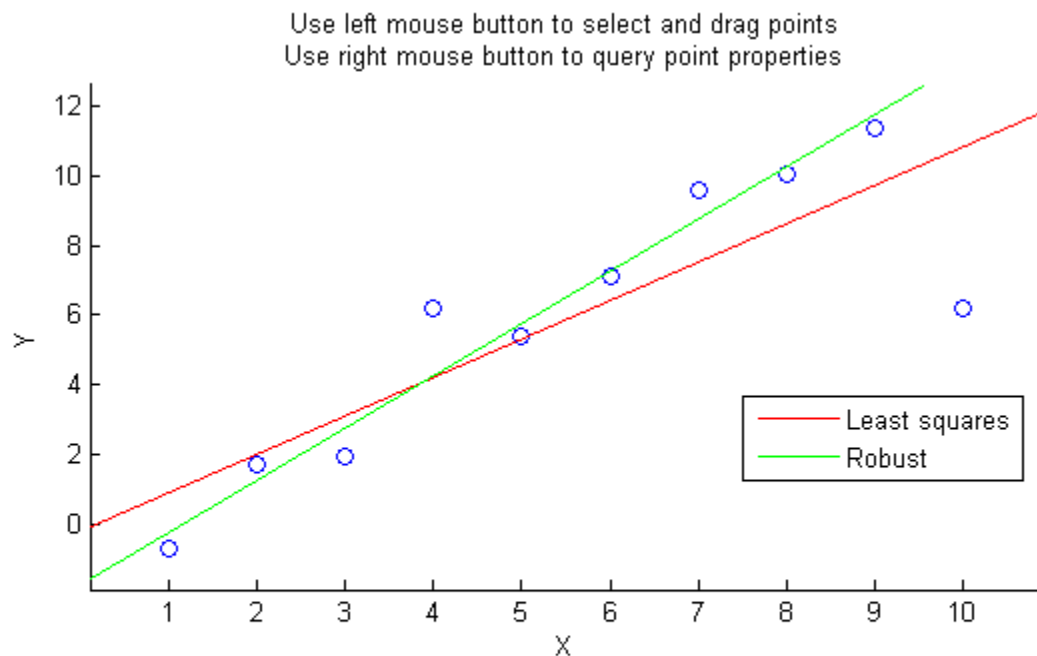
`robustdemo(x,y)` uses `x` and `y` data vectors you supply, in place of the sample data supplied with the function.

Examples The following steps show you how to use `robustdemo`.

1 Start the example. To begin using `robustdemo` with the built-in data, simply type the function name:

```
robustdemo
```

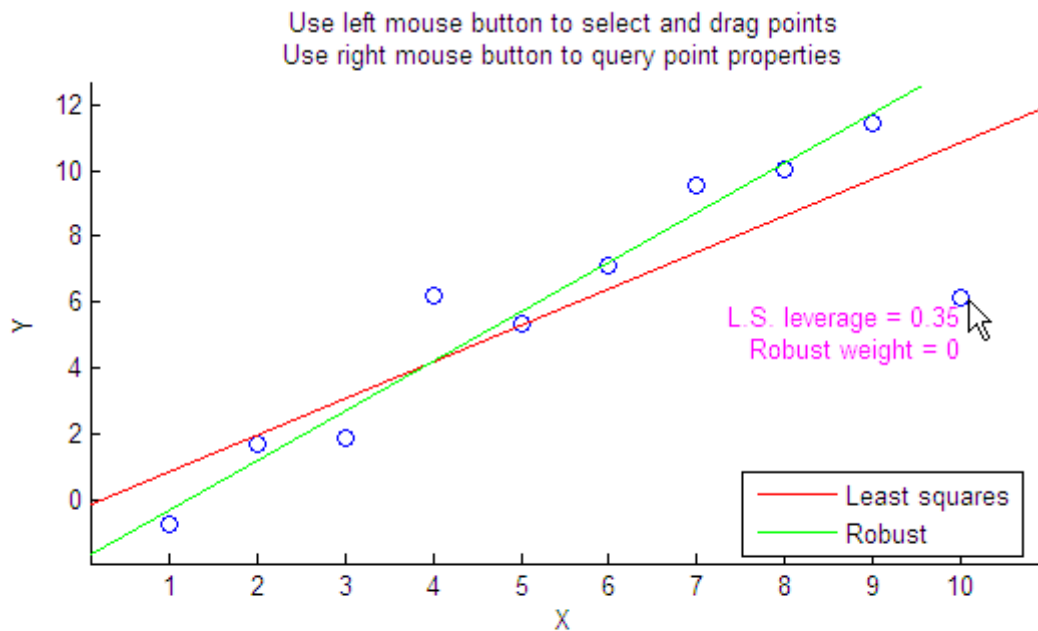
robustdemo



Least squares:	$Y = -0.188327 + 1.10351 * X$	RMS error = 2.21375
Robust:	$Y = -1.77278 + 1.50415 * X$	RMS error = 1.43663

The resulting figure shows a scatter plot with two fitted lines. The red line is the fit using ordinary least-squares regression. The green line is the fit using robust regression. At the bottom of the figure are the equations for the fitted lines, together with the estimated root mean squared errors for each fit.

2 View leverages and robust weights. Right-click on any data point to see its least-squares leverage and robust weight:



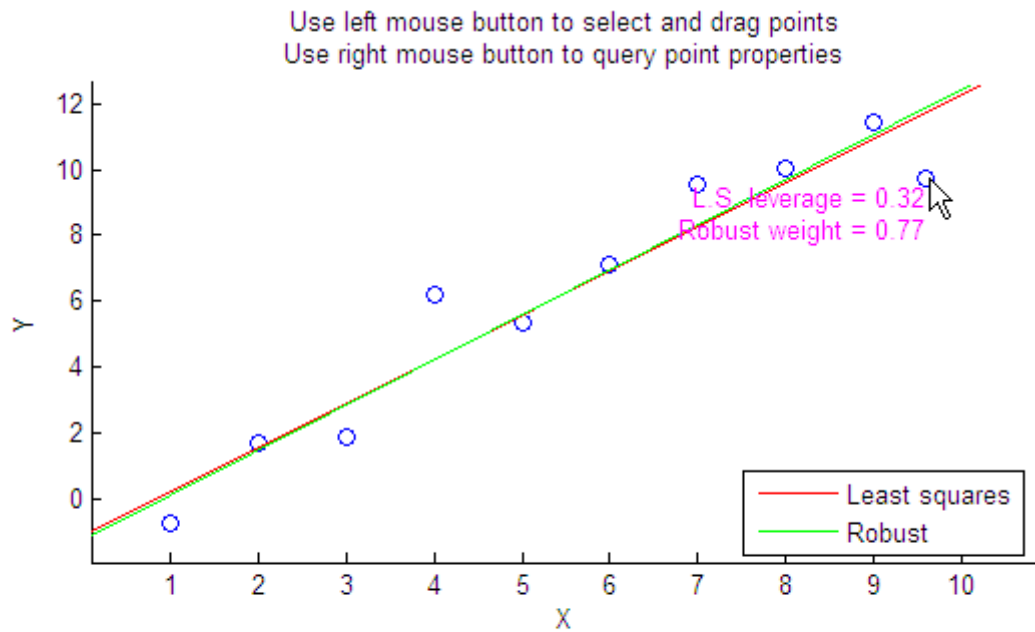
Least squares: $Y = -0.188327 + 1.10351 \cdot X$ RMS error = 2.21375

Robust: $Y = -1.77278 + 1.50415 \cdot X$ RMS error = 1.43663

In the built-in data, the right-most point has a relatively high leverage of 0.35. The point exerts a large influence on the least-squares fit, but its small robust weight shows that it is effectively excluded from the robust fit.

- 3 See how changes in the data affect the fits.** With the left mouse button, click and hold on any data point and drag it to a new location. When you release the mouse button, the displays update:

robustdemo



Least squares:	$Y = -1.0661 + 1.33785 * X$	RMS error = 1.21477
Robust:	$Y = -1.18916 + 1.36459 * X$	RMS error = 1.27697

Bringing the right-most data point closer to the least-squares line makes the two fitted lines nearly identical. The adjusted right-most data point has significant weight in the robust fit.

See Also [robustfit](#) | [leverage](#)

Purpose

Robust regression

Syntax

```

b = robustfit(X,y)
b = robustfit(X,y,wfun,tune)
b = robustfit(X,y,wfun,tune,const)
[b,stats] = robustfit(...)

```

Description

`b = robustfit(X,y)` returns a p -by-1 vector `b` of coefficient estimates for a robust multilinear regression of the responses in `y` on the predictors in `X`. `X` is an n -by- p matrix of p predictors at each of n observations. `y` is an n -by-1 vector of observed responses. By default, the algorithm uses iteratively reweighted least squares with a bisquare weighting function.

Note By default, `robustfit` adds a first column of 1s to `X`, corresponding to a constant term in the model. Do not enter a column of 1s directly into `X`. You can change the default behavior of `robustfit` using the input `const`, below.

`robustfit` treats NaNs in `X` or `y` as missing values, and removes them.

`b = robustfit(X,y,wfun,tune)` specifies a weighting function `wfun`. `tune` is a tuning constant that is divided into the residual vector before computing weights.

The weighting function `wfun` can be any one of the following strings:

Weight Function	Equation	Default Tuning Constant
'andrews'	$w = (\text{abs}(r) < \pi) .* \sin(r) ./ r$	1.339
'bisquare' (default)	$w = (\text{abs}(r) < 1) .* (1 - r.^2).^2$	4.685
'cauchy'	$w = 1 ./ (1 + r.^2)$	2.385

Weight Function	Equation	Default Tuning Constant
'fair'	$w = 1 ./ (1 + \text{abs}(r))$	1.400
'huber'	$w = 1 ./ \max(1, \text{abs}(r))$	1.345
'logistic'	$w = \tanh(r) ./ r$	1.205
'ols'	Ordinary least squares (no weighting function)	None
'talwar'	$w = 1 * (\text{abs}(r) < 1)$	2.795
'welsch'	$w = \exp(-(r.^2))$	2.985

If `tune` is unspecified, the default value in the table is used. Default tuning constants give coefficient estimates that are approximately 95% as statistically efficient as the ordinary least-squares estimates, provided the response has a normal distribution with no outliers. Decreasing the tuning constant increases the downweight assigned to large residuals; increasing the tuning constant decreases the downweight assigned to large residuals.

The value r in the weight functions is

$$r = \text{resid} / (\text{tune} * s * \sqrt{1-h})$$

where `resid` is the vector of residuals from the previous iteration, `h` is the vector of leverage values from a least-squares fit, and `s` is an estimate of the standard deviation of the error term given by

$$s = \text{MAD} / 0.6745$$

Here `MAD` is the median absolute deviation of the residuals from their median. The constant 0.6745 makes the estimate unbiased for the normal distribution. If there are p columns in X , the smallest p absolute deviations are excluded when computing the median.

You can write your own weight function. The function must take a vector of scaled residuals as input and produce a vector of weights as

output. In this case, *wfun* is specified using a function handle @ (as in @myfun), and the input *tune* is required.

`b = robustfit(X,y,wfun,tune,const)` controls whether or not the model will include a constant term. *const* is 'on' to include the constant term (the default), or 'off' to omit it. When *const* is 'on', `robustfit` adds a first column of 1s to *X*. When *const* is 'off', `robustfit` does not alter *X*.

`[b,stats] = robustfit(...)` returns the structure *stats*, whose fields contain diagnostic statistics from the regression. The fields of *stats* are:

- `ols_s` — Sigma estimate (RMSE) from ordinary least squares
- `robust_s` — Robust estimate of sigma
- `mad_s` — Estimate of sigma computed using the median absolute deviation of the residuals from their median; used for scaling residuals during iterative fitting
- `s` — Final estimate of sigma, the larger of `robust_s` and a weighted average of `ols_s` and `robust_s`
- `resid` — Residual
- `rstud` — Studentized residual (see `regress` for more information)
- `se` — Standard error of coefficient estimates
- `covb` — Estimated covariance matrix for coefficient estimates
- `coeffcorr` — Estimated correlation of coefficient estimates
- `t` — Ratio of `b` to `se`
- `p` — *p*-values for `t`
- `w` — Vector of weights for robust fit
- `R` — *R* factor in *QR* decomposition of *X*
- `dfe` — Degrees of freedom for error
- `h` — Vector of leverage values for least-squares fit

robustfit

The `robustfit` function estimates the variance-covariance matrix of the coefficient estimates using $\text{inv}(X'X) * \text{stats}.s^2$. Standard errors and correlations are derived from this estimate.

Examples

Generate data with the trend $y = 10 - 2 * x$, then change one value to simulate an outlier:

```
x = (1:10)';  
y = 10 - 2*x + randn(10,1);  
y(10) = 0;
```

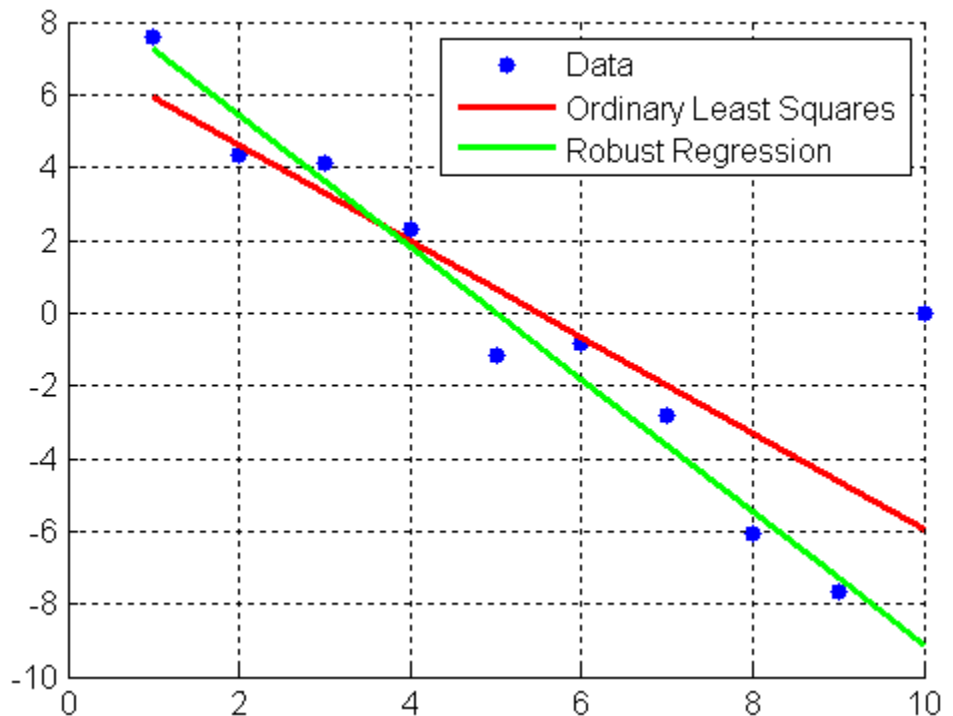
Use both ordinary least squares and robust regression to estimate a straight-line fit:

```
bls = regress(y,[ones(10,1) x])  
bls =  
    7.2481  
   -1.3208
```

```
brob = robustfit(x,y)  
brob =  
    9.1063  
   -1.8231
```

A scatter plot of the data together with the fits shows that the robust fit is less influenced by the outlier than the least-squares fit:

```
scatter(x,y,'filled'); grid on; hold on  
plot(x,bls(1)+bls(2)*x,'r','LineWidth',2);  
plot(x,brob(1)+brob(2)*x,'g','LineWidth',2)  
legend('Data','Ordinary Least Squares','Robust Regression')
```



References

- [1] DuMouchel, W. H., and F. L. O'Brien. "Integrating a Robust Option into a Multiple Regression Computing Environment." *Computer Science and Statistics: Proceedings of the 21st Symposium on the Interface*. Alexandria, VA: American Statistical Association, 1989.
- [2] Holland, P. W., and R. E. Welsch. "Robust Regression Using Iteratively Reweighted Least-Squares." *Communications in Statistics: Theory and Methods*, A6, 1977, pp. 813–827.
- [3] Huber, P. J. *Robust Statistics*. Hoboken, NJ: John Wiley & Sons, Inc., 1981.

[4] Street, J. O., R. J. Carroll, and D. Ruppert. “A Note on Computing Robust Regression Estimates via Iteratively Reweighted Least Squares.” *The American Statistician*. Vol. 42, 1988, pp. 152–154.

See Also

`regress` | `robustdemo`

Purpose Rotate categorical matrix 90 degrees

Syntax B = rot90(A)
B = rot90(A,k)

Description B = rot90(A) returns the 90 degree counterclockwise rotation of the 2-D categorical matrix A.

B = rot90(A,k) returns the $k \times 90$ degree rotation of A, $k = +1, +2, \dots$

See Also flipdim | flipplr | flipud

rotatefactors

Purpose

Rotate factor loadings

Syntax

```
B = rotatefactors(A)
B = rotatefactors(A, 'Method', 'orthomax', 'Coeff', gamma)
B = rotatefactors(A, 'Method', 'procrustes', 'Target', target)
B = rotatefactors(A, 'Method', 'pattern', 'Target', target)
B = rotatefactors(A, 'Method', 'promax')
[B,T] = rotatefactors(A, ...)
```

Description

`B = rotatefactors(A)` rotates the d -by- m loadings matrix A to maximize the varimax criterion, and returns the result in B . Rows of A and B correspond to variables and columns correspond to factors, for example, the (i, j) th element of A is the coefficient for the i th variable on the j th factor. The matrix A usually contains principal component coefficients created with `pca` or `pcacov`, or factor loadings estimated with `factoran`.

`B = rotatefactors(A, 'Method', 'orthomax', 'Coeff', gamma)` rotates A to maximize the orthomax criterion with the coefficient `gamma`, i.e., B is the orthogonal rotation of A that maximizes

$$\text{sum}(D * \text{sum}(B.^4, 1) - \text{GAMMA} * \text{sum}(B.^2, 1).^2)$$

The default value of 1 for `gamma` corresponds to varimax rotation. Other possibilities include `gamma = 0`, `m/2`, and `d(m - 1)/(d + m - 2)`, corresponding to quartimax, equamax, and parsimax. You can also supply the strings `'varimax'`, `'quartimax'`, `'equamax'`, or `'parsimax'` for the `'method'` parameter and omit the `'Coeff'` parameter.

If `'Method'` is `'orthomax'`, `'varimax'`, `'quartimax'`, `'equamax'`, or `'parsimax'`, then additional parameters are

- `'Normalize'` — Flag indicating whether the loadings matrix should be row-normalized for rotation. If `'on'` (the default), rows of A are normalized prior to rotation to have unit Euclidean norm, and unnormalized after rotation. If `'off'`, the raw loadings are rotated and returned.

- 'Reltol' — Relative convergence tolerance in the iterative algorithm used to find T. The default is $\sqrt{\text{eps}}$.
- 'Maxit' — Iteration limit in the iterative algorithm used to find T. The default is 250.

`B = rotatefactors(A, 'Method', 'procrustes', 'Target', target)` performs an oblique procrustes rotation of A to the *d*-by-*m* target loadings matrix target.

`B = rotatefactors(A, 'Method', 'pattern', 'Target', target)` performs an oblique rotation of the loadings matrix A to the *d*-by-*m* target pattern matrix target, and returns the result in B. target defines the "restricted" elements of B, i.e., elements of B corresponding to zero elements of target are constrained to have small magnitude, while elements of B corresponding to nonzero elements of target are allowed to take on any magnitude.

If 'Method' is 'procrustes' or 'pattern', an additional parameter is 'Type', the type of rotation. If 'Type' is 'orthogonal', the rotation is orthogonal, and the factors remain uncorrelated. If 'Type' is 'oblique' (the default), the rotation is oblique, and the rotated factors might be correlated.

When 'Method' is 'pattern', there are restrictions on target. If A has *m* columns, then for orthogonal rotation, the *j*th column of target must contain at least $m - j$ zeros. For oblique rotation, each column of target must contain at least $m - 1$ zeros.

`B = rotatefactors(A, 'Method', 'promax')` rotates A to maximize the promax criterion, equivalent to an oblique Procrustes rotation with a target created by an orthomax rotation. Use the four orthomax parameters to control the orthomax rotation used internally by promax.

An additional parameter for 'promax' is 'Power', the exponent for creating promax target matrix. 'Power' must be 1 or greater. The default is 4.

`[B,T] = rotatefactors(A,...)` returns the rotation matrix T used to create B, that is, $B = A * T$. You can find the correlation matrix of the rotated factors by using `inv(T'*T)`. For orthogonal rotation, this is the

rotatefactors

identity matrix, while for oblique rotation, it has unit diagonal elements but nonzero off-diagonal elements.

Examples

```
rng('default') % for reproducibility
X = randn(100,10);

% Default (normalized varimax) rotation:
% first three principle components.
LPC = pca(X);
[L1,T] = rotatefactors(LPC(:,1:3));

% Equamax rotation:
% first three principle components.
[L2,T] = rotatefactors(LPC(:,1:3),...
                      'method','equamax');

% Promax rotation:
% first three factors.
LFA = factoran(X,3,'Rotate','none');
[L3,T] = rotatefactors(LFA(:,1:3),...
                      'method','promax',...
                      'power',2);

% Pattern rotation:
% first three factors.
Tgt = [1 1 1 1 1 0 1 0 1 1; ...
       0 0 0 1 1 1 0 0 0 0; ...
       1 0 0 1 0 1 1 1 1 0]';
[L4,T] = rotatefactors(LFA(:,1:3),...
                      'method','pattern',...
                      'target',Tgt);
inv(T'*T) % Correlation matrix of the rotated factors
ans =

    1.0000   -0.9593   -0.7098
   -0.9593    1.0000    0.5938
   -0.7098    0.5938    1.0000
```

References

[1] Harman, H. H. *Modern Factor Analysis*. 3rd ed. Chicago: University of Chicago Press, 1976.

[2] Lawley, D. N., and A. E. Maxwell. *Factor Analysis as a Statistical Method*. 2nd ed. New York: American Elsevier Publishing, 1971.

See Also

[biplot](#) | [factoran](#) | [pca](#) | [pcacov](#) | [procrustes](#)

Purpose Row exchange

Syntax

```
dRE = rowexch(nfactors, nruns)
[dRE, X] = rowexch(nfactors, nruns)
[dRE, X] = rowexch(nfactors, nruns, model)
[dRE, X] = rowexch(..., param1, val1, param2, val2, ...)
```

Description `dRE = rowexch(nfactors, nruns)` uses a row-exchange algorithm to generate a D -optimal design `dRE` with `nruns` runs (the rows of `dRE`) for a linear additive model with `nfactors` factors (the columns of `dRE`). The model includes a constant term.

`[dRE, X] = rowexch(nfactors, nruns)` also returns the associated design matrix X , whose columns are the model terms evaluated at each treatment (row) of `dRE`.

`[dRE, X] = rowexch(nfactors, nruns, model)` uses the linear regression model specified in `model`. `model` is one of the following strings:

- 'linear' — Constant and linear terms. This is the default.
- 'interaction' — Constant, linear, and interaction terms
- 'quadratic' — Constant, linear, interaction, and squared terms
- 'purequadratic' — Constant, linear, and squared terms

The order of the columns of X for a full quadratic model with n terms is:

- 1** The constant term
- 2** The linear terms in order 1, 2, ..., n
- 3** The interaction terms in order (1, 2), (1, 3), ..., (1, n), (2, 3), ..., ($n-1$, n)
- 4** The squared terms in order 1, 2, ..., n

Other models use a subset of these terms, in the same order.

Alternatively, *model* can be a matrix specifying polynomial terms of arbitrary order. In this case, *model* should have one column for each factor and one row for each term in the model. The entries in any row of *model* are powers for the factors in the columns. For example, if a model has factors *X1*, *X2*, and *X3*, then a row [0 1 2] in *model* specifies the term $(X1.^0) \cdot (X2.^1) \cdot (X3.^2)$. A row of all zeros in *model* specifies a constant term, which can be omitted.

[dRE,X] = rowexch(..., *param1*, *val1*, *param2*, *val2*, ...) specifies additional parameter/value pairs for the design. Valid parameters and their values are listed in the following table.

Parameter	Value
'bounds'	Lower and upper bounds for each factor, specified as a 2-by-nfactors matrix. Alternatively, this value can be a cell array containing nfactors elements, each element specifying the vector of allowable values for the corresponding factor.
'categorical'	Indices of categorical predictors.
'display'	Either 'on' or 'off' to control display of the iteration counter. The default is 'on'.
'excludedefun'	Handle to a function that excludes undesirable runs. If the function is <i>f</i> , it must support the syntax $b = f(S)$, where <i>S</i> is a matrix of treatments with nfactors columns and <i>b</i> is a vector of Boolean values with the same number of rows as <i>S</i> . <i>b</i> (<i>i</i>) is true if the <i>i</i> th row <i>S</i> should be excluded.
'init'	Initial design as an nruns-by-nfactors matrix. The default is a randomly selected set of points.
'levels'	Vector of number of levels for each factor.
'maxiter'	Maximum number of iterations. The default is 10.

Parameter	Value
options	<p>A structure that specifies whether to run in parallel, and specifies the random stream or streams. Create the options structure with <code>statset</code>. Option fields:</p> <ul style="list-style-type: none"> • <code>UseParallel</code> — Set to 'always' to compute in parallel. Default is 'never'. • <code>UseSubstreams</code> — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set <code>Streams</code> to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'. • <code>Streams</code> — A <code>RandStream</code> object or cell array of such objects. If you do not specify <code>Streams</code>, <code>rowexch</code> uses the default stream or streams. If you choose to specify <code>Streams</code>, use a single object except in the case <ul style="list-style-type: none"> ▪ You have an open MATLAB pool ▪ <code>UseParallel</code> is 'always' ▪ <code>UseSubstreams</code> is 'never' <p>In that case, use a cell array the same size as the MATLAB pool.</p>
'tries'	<p>Number of times to try to generate a design from a new starting point. The algorithm uses random points for each try, except possibly the first. The default is 1.</p>

Algorithms

Both `cordexch` and `rowexch` use iterative search algorithms. They operate by incrementally changing an initial design matrix X to increase $D = |X^T X|$ at each step. In both algorithms, there is randomness built into the selection of the initial design and into the choice of the incremental changes. As a result, both algorithms may return locally, but not globally, D -optimal designs. Run each algorithm multiple times

and select the best result for your final design. Both functions have a 'tries' parameter that automates this repetition and comparison.

At each step, the row-exchange algorithm exchanges an entire row of X with a row from a design matrix C evaluated at a candidate set of feasible treatments. The rowexch function automatically generates a C appropriate for a specified model, operating in two steps by calling the candgen and candexch functions in sequence. Provide your own C by calling candexch directly. In either case, if C is large, its static presence in memory can affect computation.

Examples

Suppose you want a design to estimate the parameters in the following three-factor, seven-term interaction model:

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{23}x_2x_3 + \varepsilon$$

Use rowexch to generate a D -optimal design with seven runs:

```
nfactors = 3;
nruns = 7;
[dRE,X] = rowexch(nfactors,nruns,'interaction','tries',10)
dRE =
    -1    -1     1
     1    -1     1
     1    -1    -1
     1     1     1
    -1    -1    -1
    -1     1    -1
    -1     1     1
X =
     1    -1    -1     1     1    -1    -1
     1     1    -1     1    -1     1    -1
     1     1    -1    -1    -1    -1     1
     1     1     1     1     1     1     1
     1    -1    -1    -1     1     1     1
     1    -1     1    -1    -1     1    -1
     1    -1     1     1    -1    -1     1
```

rowexch

Columns of the design matrix X are the model terms evaluated at each row of the design dRE . The terms appear in order from left to right: constant term, linear terms (1, 2, 3), interaction terms (12, 13, 23). Use X to fit the model, as described in “Linear Regression” on page 9-7, to response data measured at the design points in dRE .

See Also

candgen | candexch | cordexch

Purpose Interactive response surface demonstration

Syntax rsmdemo

Description rsmdemo opens a group of three graphical user interfaces for interactively investigating response surface methodology (RSM), nonlinear fitting, and the design of experiments.

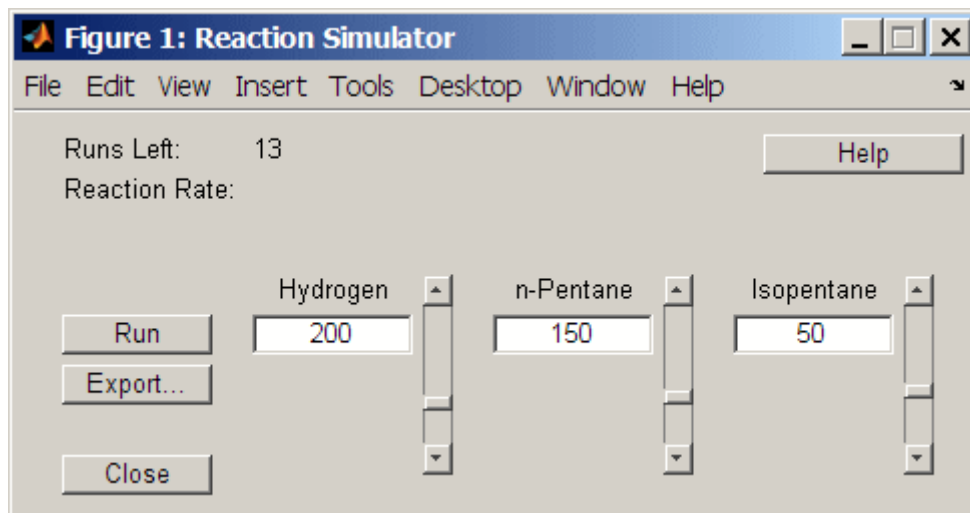
The interfaces allow you to collect and model data from a simulated chemical reaction. Experimental predictors are concentrations of three reactants (hydrogen, *n*-Pentane, and isopentane) and the response is the reaction rate. The reaction rate is simulated by a Hougen-Watson model (Bates and Watts, [2], pp. 271–272):

$$rate = \frac{\beta_1 x_2 - x_3 / \beta_5}{1 + \beta_2 x_1 + \beta_3 x_2 + \beta_4 x_3}$$

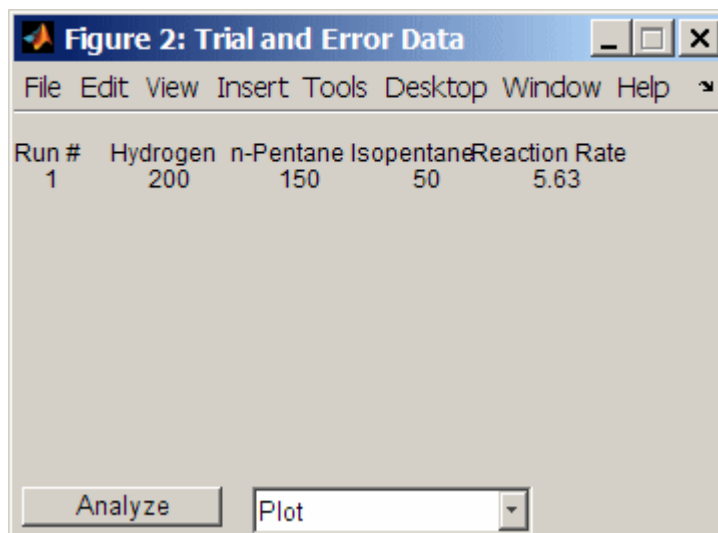
where *rate* is the reaction rate, x_1 , x_2 , and x_3 are the concentrations of hydrogen, *n*-pentane, and isopentane, respectively, and $\beta_1, \beta_2, \dots, \beta_5$ are fixed parameters. Random errors are used to perturb the reaction rate for each combination of reactants.

Collect data using one of two methods:

- 1 Manually set reactant concentrations in the **Reaction Simulator** interface by editing the text boxes or by adjusting the associated sliders.

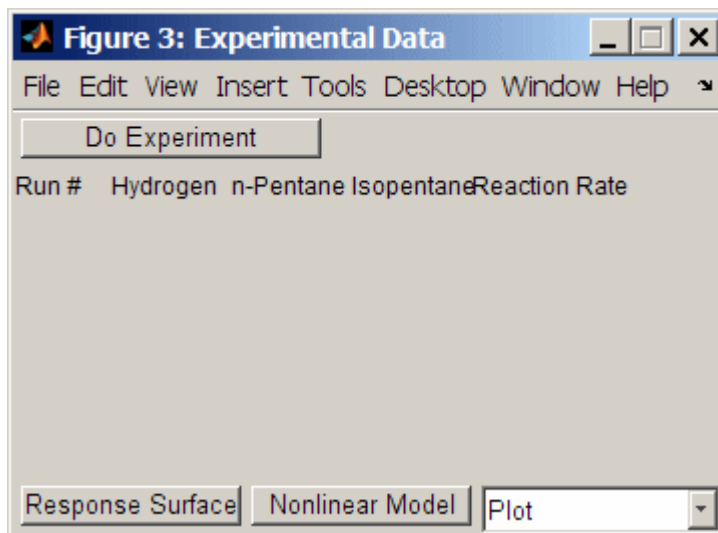


When you click **Run**, the concentrations and simulated reaction rate are recorded on the **Trial and Error Data** interface.

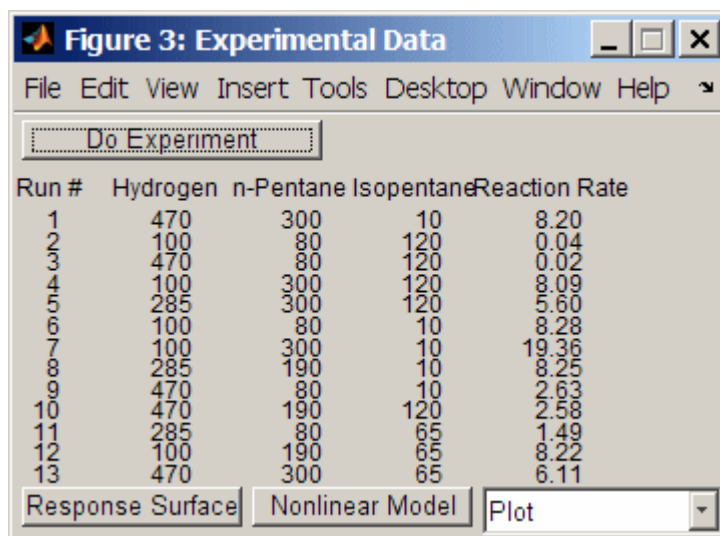


You are allowed up to 13 independent experimental runs for data collection.

- 2 Use a designed experiment to set reactant concentrations in the **Experimental Data** interface by clicking the **Do Experiment** button.



A 13-run *D*-optimal design for a full quadratic model is generated by the `cordexch` function, and the concentrations and simulated reaction rates are recorded on the same interface.



Once data is collected, scatter plots of reaction rates vs. individual predictors are generated by selecting one of the following from the **Plot** pop-up menu below the recorded data:

- **Hydrogen vs. Rate**
- **n-Pentane vs. Rate**
- **Isopentane vs. Rate**

Fit a response surface model to the data by clicking the **Analyze** button below the trial-and-error data or the **Response Surface** button below the experimental data. Both buttons load the data into the Response Surface Tool `rstool`. By default, trial-and-error data is fit with a linear additive model and experimental data is fit with a full quadratic model, but the models can be adjusted in the Response Surface Tool.

For experimental data, you have the additional option of fitting a Hougen-Watson model. Click the **Nonlinear Model** button to load the data and the model in `hougen` into the Nonlinear Fitting Tool `nlintool`.

See Also

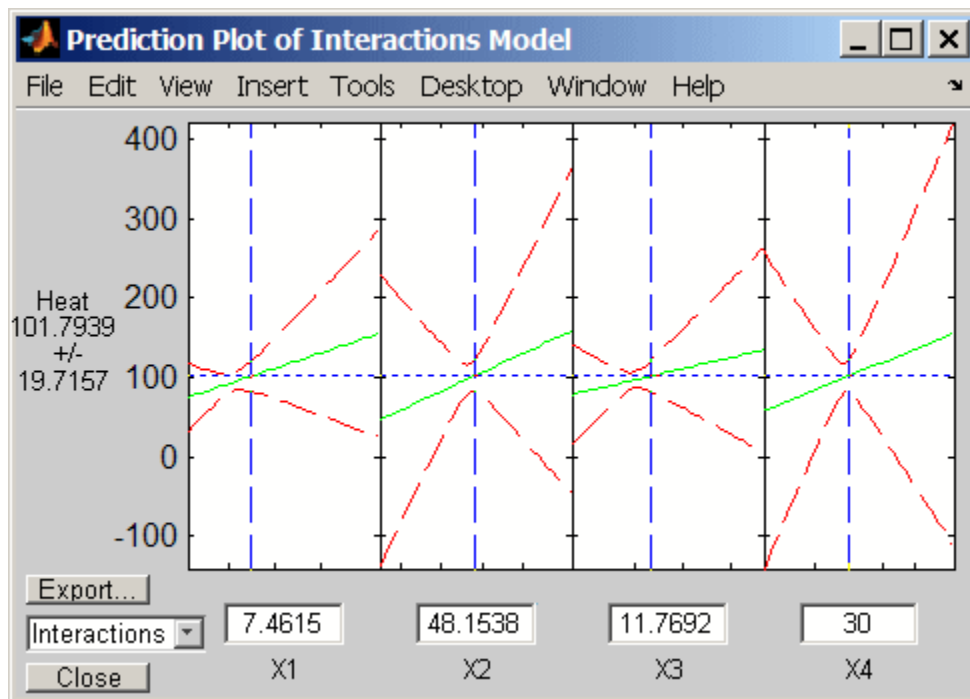
hougen | cordexch | rstool | nlintool

rstool

Purpose Interactive response surface modeling

Syntax
`rstool`
`rstool(X,Y,model)`
`rstool(x,y,model,alpha)`
`rstool(x,y,model,alpha,xname,yname)`

Description `rstool` opens a graphical user interface for interactively investigating one-dimensional contours of multidimensional response surface models.



By default, the interface opens with the data from `hald.mat` and a fitted response surface with constant, linear, and interaction terms.

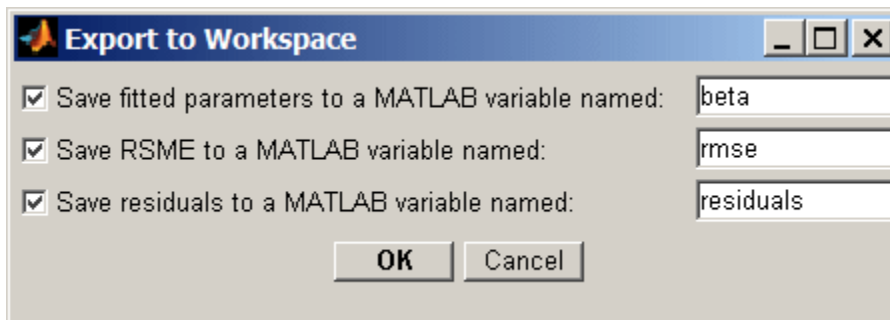
A sequence of plots is displayed, each showing a contour of the response surface against a single predictor, with all other predictors held fixed.

rstool plots a 95% simultaneous confidence band for the fitted response surface as two red curves. Predictor values are displayed in the text boxes on the horizontal axis and are marked by vertical dashed blue lines in the plots. Predictor values are changed by editing the text boxes or by dragging the dashed blue lines. When you change the value of a predictor, all plots update to show the new point in predictor space.

The pop-up menu at the lower left of the interface allows you to choose among the following models:

- Linear — Constant and linear terms (the default)
- Pure Quadratic — Constant, linear, and squared terms
- Interactions — Constant, linear, and interaction terms
- Full Quadratic — Constant, linear, interaction, and squared terms

Click **Export** to open the following dialog box:



The dialog allows you to save information about the fit to MATLAB workspace variables with valid names.

`rstool(X,Y,model)` opens the interface with the predictor data in *X*, the response data in *Y*, and the fitted model *model*. Distinct predictor variables should appear in different columns of *X*. *Y* can be a vector, corresponding to a single response, or a matrix, with columns corresponding to multiple responses. *Y* must have as many elements (or rows, if it is a matrix) as *X* has rows.

The optional input *model* can be any one of the following strings:

- 'linear' — Constant and linear terms (the default)
- 'purequadratic' — Constant, linear, and squared terms
- 'interaction' — Constant, linear, and interaction terms
- 'quadratic' — Constant, linear, interaction, and squared terms

To specify a polynomial model of arbitrary order, or a model without a constant term, use a matrix for *model* as described in `x2fx`.

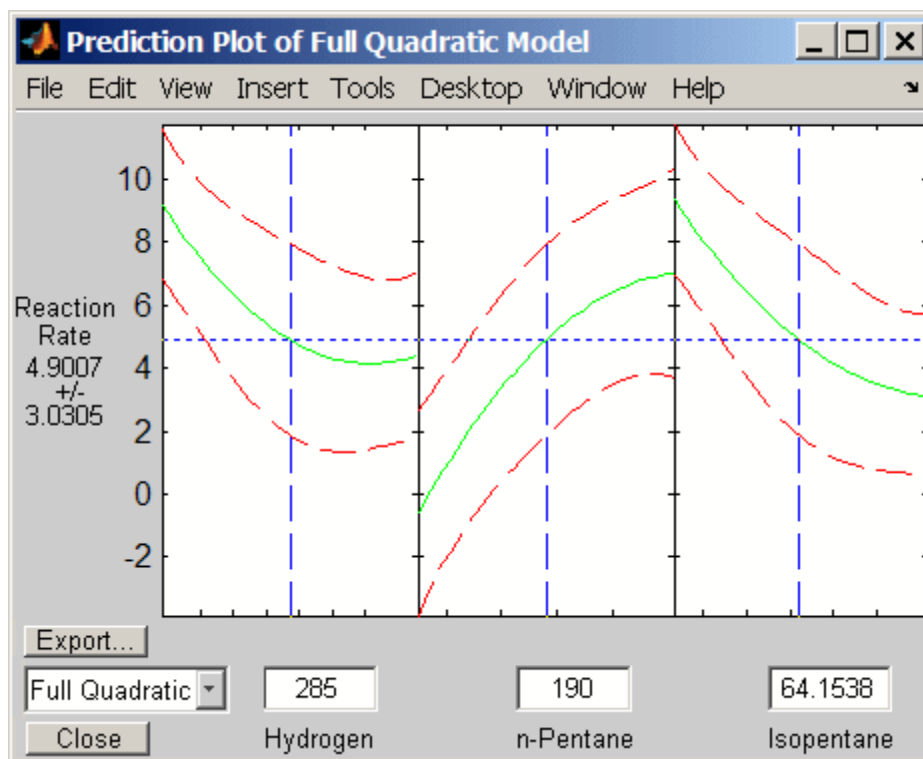
`rstool(x,y,model,alpha)` uses $100(1-\alpha)\%$ global confidence intervals for new observations in the plots.

`rstool(x,y,model,alpha,xname,yname)` labels the axes using the strings in *xname* and *yname*. To label each subplot differently, *xname* and *yname* can be cell arrays of strings.

Examples

The following uses `rstool` to visualize a quadratic response surface model of the 3-D chemical reaction data in `reaction.mat`:

```
load reaction
alpha = 0.01; % Significance level
rstool(reactants,rate,'quadratic',alpha,xn,yn)
```

The rstool interface is used by rsmdemo to visualize the results of simulated experiments with data like that in reaction.mat. As described in “Response Surface Designs” on page 15-9, rsmdemo uses a response surface model to generate simulated data at combinations of predictors specified by either the user or by a designed experiment.

See Also

x2fx | rsmdemo | nlintool

runstest

Purpose Run test for randomness

Syntax

```
h = runstest(x)
h = runstest(x,v)
h = runstest(x,'ud')
h = runstest(...,param1,val1,param2,val2,...)
[h,p] = runstest(...)
[h,p,stats] = runstest(...)
```

Description `h = runstest(x)` performs a runs test on the sequence of observations in the vector `x`. This is a test of the null hypothesis that the values in `x` come in random order, against the alternative that they do not. The test is based on the number of runs of consecutive values above or below the mean of `x`. Too few runs indicate a tendency for high and low values to cluster. Too many runs indicate a tendency for high and low values to alternate. The test returns the logical value `h = 1` if it rejects the null hypothesis at the 5% significance level, and `h = 0` if it cannot. The test treats NaN values in `x` as missing values, and ignores them.

`runstest` uses a test statistic which is approximately normally distributed when the null hypothesis is true. It is the difference between the number of runs and its mean, divided by its standard deviation.

`h = runstest(x,v)` performs the test using runs above or below the value `v`. Values exactly equal to `v` are discarded. The default value of `v` is the mean of `x`.

`h = runstest(x,'ud')` performs a test for the number of runs up or down. This also tests the hypothesis that the values in `x` come in random order. Too few runs indicate a trend. Too many runs indicate an oscillation. Values exactly equal to the preceding value are discarded.

`h = runstest(...,param1,val1,param2,val2,...)` specifies additional parameters and their values. Valid parameter/value pairs are the following:

- 'alpha' — A scalar giving the significance level of the test
- 'method' — Either 'exact' to compute the p value using an exact algorithm, or 'approximate' to use a normal approximation. The

default is 'exact', except for runs up/down when the length of x is 51 or more. The 'exact' method is not available for runs up/down when the length of x is over 50.

- 'tail' — Performs the test against one of the following alternative hypotheses:
 - 'both' — two-tailed test (sequence is not random)
 - 'right' — right-tailed test (like values separate for runs above/below, direction alternates for runs up/down)
 - 'left' — left-tailed test (like values cluster for runs above/below, values trend for runs up/down)

`[h,p] = runstest(...)` returns the p value of the test. The output p is computed from either the test statistic or the exact distribution of the number of runs, depending on the value of the 'method' parameter.

`[h,p,stats] = runstest(...)` returns a structure `stats` with the following fields:

- `nruns` — The number of runs
- `n1` — The number of values above v
- `n0` — The number of values below v
- `z` — The test statistic

Examples

```
x = randn(40,1);  
[h,p] = runstest(x,median(x))  
h =  
    0  
p =  
    0.6286
```

See Also

`signrank` | `signtest`

TreeBagger.SampleWithReplacement property

Purpose Flag to sample with replacement

Description The SampleWithReplacement property is a logical flag specifying if data are sampled for each decision tree with replacement. True if TreeBagger samples data with replacement and false otherwise. True by default.

Purpose

Sample size and power of test

Syntax

```
n = sampsizepwr(testtype,p0,p1)
n = sampsizepwr(testtype,p0,p1,power)
power = sampsizepwr(testtype,p0,p1,[],n)
p1 = sampsizepwr(testtype,p0,[],power,n)
[...] = sampsizepwr(...,n,param1,va11,param2,va12,...)
```

Description

`n = sampsizepwr(testtype,p0,p1)` returns the sample size n required for a two-sided test of the specified type to have a power (probability of rejecting the null hypothesis when the alternative hypothesis is true) of 0.90 when the significance level (probability of rejecting the null hypothesis when the null hypothesis is true) is 0.05. `p0` specifies parameter values under the null hypothesis. `p1` specifies the single parameter value being tested under the alternative hypothesis.

The following values are available for `testtype`:

- 'z' — z -test for normally distributed data with known standard deviation. `p0` is a two-element vector [`mu0` `sigma0`] of the mean and standard deviation, respectively, under the null hypothesis. `p1` is the value of the mean under the alternative hypothesis.
- 't' — t -test for normally distributed data with unknown standard deviation. `p0` is a two-element vector [`mu0` `sigma0`] of the mean and standard deviation, respectively, under the null hypothesis. `p1` is the value of the mean under the alternative hypothesis.
- 'var' — Chi-square test of variance for normally distributed data. `p0` is the variance under the null hypothesis. `p1` is the variance under the alternative hypothesis.
- 'p' — Test of the p parameter (success probability) for a binomial distribution. `p0` is the value of p under the null hypothesis. `p1` is the value of p under the alternative hypothesis.

The 'p' test is a discrete test for which increasing the sample size does not always increase the power. For n values larger than 200, there may be values smaller than the returned n value that also produce the desired size and power.

sampsizepwr

`n = sampsizepwr(testtype,p0,p1,power)` returns the sample size n such that the power is `power` for the parameter value `p1`.

`power = sampsizepwr(testtype,p0,p1,[],n)` returns the power achieved for a sample size of n when the true parameter value is `p1`.

`p1 = sampsizepwr(testtype,p0,[],power,n)` returns the parameter value detectable with the specified sample size n and power `power`.

When computing `p1` for the 'p' test, if no alternative can be rejected for a given null hypothesis and significance level, the function displays a warning message and returns NaN.

`[...] = sampsizepwr(...,n,param1,val1,param2,val2,...)` specifies one or more of the following name/value pairs:

- 'alpha' — Significance level of the test (default 0.05)
- 'tail' — The type of test is one of the following:
 - 'both' — Two-sided test for an alternative not equal to p_0
 - 'right' — One-sided test for an alternative larger than p_0
 - 'left' — One-sided test for an alternative smaller than p_0

Examples

Compute the mean closest to 100 that can be determined to be significantly different from 100 using a t -test with a sample size of 60 and a power of 0.8.

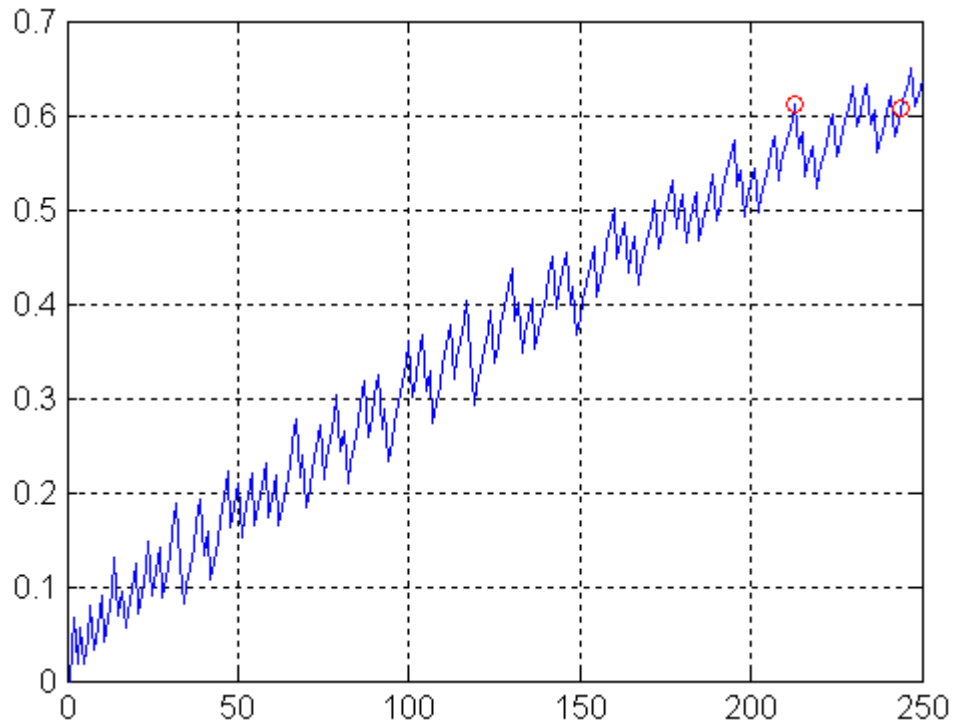
```
mu1 = sampsizepwr('t',[100 10],[],0.8,60)
mu1 =
    103.6770
```

Compute the sample size n required to distinguish $p = 0.26$ from $p = 0.6$ with a binomial test. The result is approximate, so make a plot to see if any smaller n values also have the required power of 0.5.

```
napprox = sampsizepwr('p',0.2,0.26,0.6)
Warning: Values N>200 are approximate. Plotting the power as a function
of N may reveal lower N values that have the required power.
napprox =
```

244

```
nn = 1:250;  
pwr = sampsizewr('p',0.2,0.26,[],nn);  
nexact = min(nn(pwr>=0.6))  
nexact =  
    213  
  
plot(nn,pwr,'b-',[napprox nexact],pwr([napprox nexact]),'ro');  
grid on
```

**See Also**

vartest | ttest | ztest | binocdf

scatterhist

Purpose

Scatter plot with marginal histograms

Syntax

```
scatterhist(x,y)
h = scatterhist(...)
scatterhist(...,'param1',val1,'param2',val2,...)
```

Description

`scatterhist(x,y)` creates a 2-D scatterplot of the data in the vectors `x` and `y`, and puts a univariate histogram on the horizontal and vertical axes of the plot. `x` and `y` must be the same length.

The function is useful for viewing properties of random samples produced by functions such as `copularnd`, `mvnrnd`, `lhsdesign`.

`h = scatterhist(...)` returns a vector of three axes handles for the scatterplot, the histogram along the horizontal axis, and the histogram along the vertical axis, respectively.

`scatterhist(...,'param1',val1,'param2',val2,...)` specifies additional parameter name/values pairs to control how the plot is made. Valid parameters are the following:

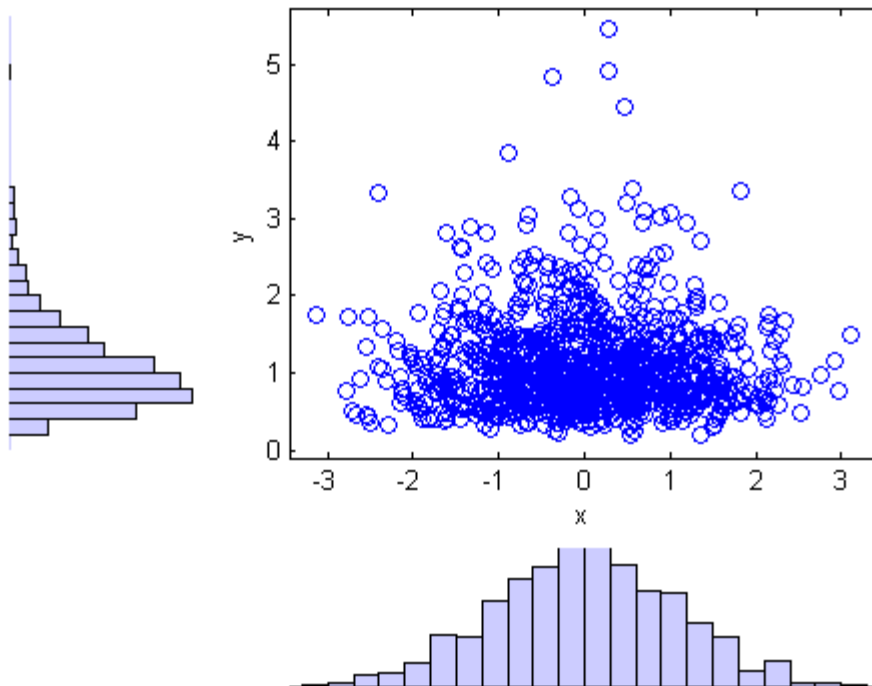
- `'NBins'` — A scalar or a two-element vector specifying the number of bins for the X and Y histograms. The default is to compute the number of bins using Scott's rule based on the sample standard deviation.
- `'Location'` — A string controlling the location of the marginal histograms within the figure. `'SouthWest'` (the default) plots the histograms below and to the left of the scatterplot, `'SouthEast'` plots them below and to the right, `'NorthEast'` above and to the right, and `'NorthWest'` above and to the left.
- `'Direction'` — A string controlling the direction of the marginal histograms in the figure. `'in'` (the default) plots the histograms with bars directed in towards the scatterplot, `'out'` plots the histograms with bars directed out away from the scatterplot.

Examples

Example 1

Independent normal and lognormal random samples:


```
x = randn(1000,1);  
y = exp(.5*randn(1000,1));  
scatterhist(x,y)
```

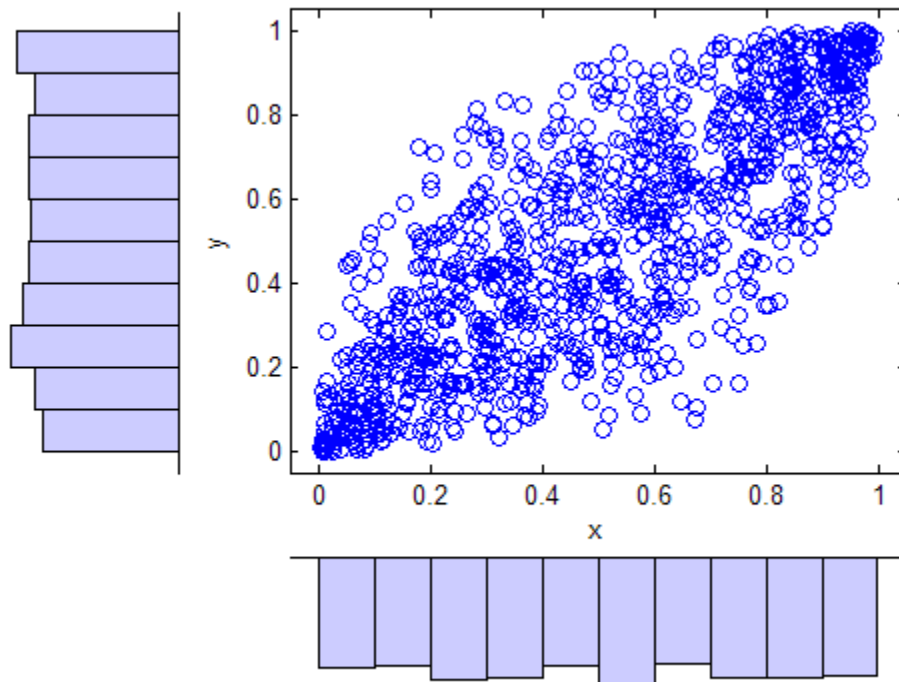


Example 2

Marginal uniform samples that are not independent:

```
u = copularnd('Gaussian',.8,1000);  
scatterhist(u(:,1),u(:,2),'Direction','out')
```

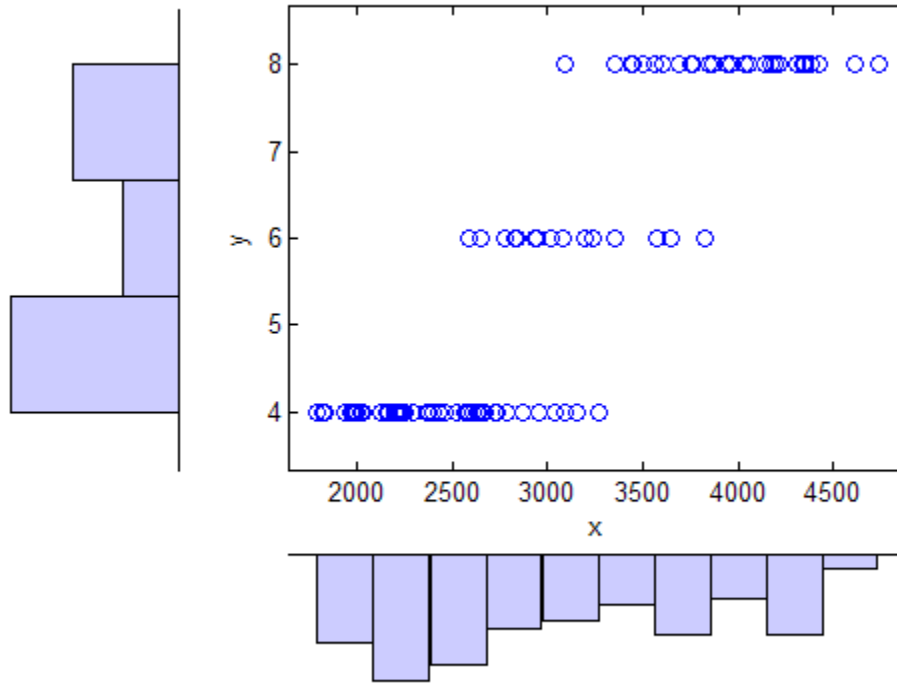
scatterhist



Example 3

Mixed discrete and continuous data:

```
load('carsmall');  
scatterhist(Weight,Cylinders,'NBins',[10 3],'Direction','out')
```



See Also `scatter` | `hist`

grandset.scramble

Purpose Scramble quasi-random point set

Syntax

```
ps = scramble(p, type)
ps = scramble(p, 'clear')
ps = scramble(p)
```

Description `ps = scramble(p, type)` returns a scrambled copy `ps` of the point set `p` of the `grandset` class, created using the scramble type specified in the string `type`. Point sets from different subclasses of `grandset` support different scramble types, as indicated in the following table.

Subclass	Scramble Types
haltonset	'RR2' — A permutation of the radical inverse coefficients derived by applying a reverse-radix operation to all of the possible coefficient values. The scramble is described in [1].
sobolset	'MatousekAffineOwen' — A random linear scramble combined with a random digital shift. The scramble is described in [2].

`ps = scramble(p, 'clear')` removes all scramble settings from `p` and returns the result in `ps`.

`ps = scramble(p)` removes all scramble settings from `p` and then adds them back in the order they were originally applied. This typically results in a different point set because of the randomness of the scrambling algorithms.

Examples Use `haltonset` to generate a 3-D Halton point set, skip the first 1000 values, and then retain every 101st point:

```
p = haltonset(3, 'Skip', 1e3, 'Leap', 1e2)
p =
  Halton point set in 3 dimensions (8.918019e+013 points)
  Properties:
    Skip : 1000
```

```
Leap : 100
ScrambleMethod : none
```

Use scramble to apply reverse-radix scrambling:

```
p = scramble(p, 'RR2')
p =
Halton point set in 3 dimensions (8.918019e+013 points)
Properties:
Skip : 1000
Leap : 100
ScrambleMethod : RR2
```

Use net to generate the first four points:

```
X0 = net(p,4)
X0 =
0.0928    0.6950    0.0029
0.6958    0.2958    0.8269
0.3013    0.6497    0.4141
0.9087    0.7883    0.2166
```

Use parenthesis indexing to generate every third point, up to the 11th point:

```
X = p(1:3:11,:)
X =
0.0928    0.6950    0.0029
0.9087    0.7883    0.2166
0.3843    0.9840    0.9878
0.6831    0.7357    0.7923
```

References

- [1] Kocis, L., and W. J. Whiten. “Computational Investigations of Low-Discrepancy Sequences.” *ACM Transactions on Mathematical Software*. Vol. 23, No. 2, 1997, pp. 266–294.
- [2] Matousek, J. “On the L2-Discrepancy for Anchored Boxes.” *Journal of Complexity*. Vol. 14, No. 4, 1998, pp. 527–556.

grandset.scramble

See Also

haltonset | sobolset

grandset.ScrambleMethod property

Purpose

Settings that control scrambling

Description

The ScrambleMethod property contains a structure that defines which scrambles to apply to the sequence. The structure consists of two fields:

- **Type:** A string containing the name of the scramble.
- **Options:** A cell array of parameter values for the scramble.

Different point sets support different scramble types as outlined in the help for each point set class. An error occurs if you set an invalid scramble type for a given point set.

The ScrambleMethod property also accepts an empty matrix as a value. This will clear all scrambling and set the property to contain a (0x0) structure.

The scramble method provides an alternative, easier way to set scrambles.

Examples

Apply a random linear scramble combined with a random digital shift to a sobolset point set class:

```
P = sobolset(5);  
P = scramble(P, 'MatousekAffineOwen');  
P.ScrambleMethod
```

See Also

sobolset | scramble

piecewisedistribution.segment

Purpose Segments containing values

Syntax `S = segment(obj,X,P)`

Description `S = segment(obj,X,P)` returns an array `S` of integers indicating which segment of the piecewise distribution object `obj` contains each value of `X` or, alternatively, `P`. One of `X` and `P` must be empty (`[]`). If `X` is nonempty, `S` is determined by comparing `X` with the quantile boundary values defined for `obj`. If `P` is nonempty, `S` is determined by comparing `P` with the probability boundary values.

Examples Fit Pareto tails to a t distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);
obj = paretotails(t,0.1,0.9);

pvals = 0:0.2:1;
s = segment(obj,[],pvals)
s =
     1     2     2     2     2     3
```

See Also `paretotails` | `boundary` | `nsegments`

Purpose

Sequential feature selection

Syntax

```
inmodel = sequentialfs(fun,X,y)
inmodel = sequentialfs(fun,X,Y,Z,...)
[inmodel,history] = sequentialfs(fun,X,...)
[] = sequentialfs(...,param1,val1,param2,val2,...)
```

Description

`inmodel = sequentialfs(fun,X,y)` selects a subset of features from the data matrix `X` that best predict the data in `y` by sequentially selecting features until there is no improvement in prediction. Rows of `X` correspond to observations; columns correspond to variables or features. `y` is a column vector of response values or class labels for each observation in `X`. `X` and `y` must have the same number of rows. `fun` is a function handle to a function that defines the criterion used to select features and to determine when to stop. The output `inmodel` is a logical vector indicating which features are finally chosen.

Starting from an empty feature set, `sequentialfs` creates candidate feature subsets by sequentially adding each of the features not yet selected. For each candidate feature subset, `sequentialfs` performs 10-fold cross-validation by repeatedly calling `fun` with different training subsets of `X` and `y`, `XTRAIN` and `ytrain`, and test subsets of `X` and `y`, `XTEST` and `ytest`, as follows:

```
criterion = fun(XTRAIN,ytrain,XTEST,ytest)
```

`XTRAIN` and `ytrain` contain the same subset of rows of `X` and `Y`, while `XTEST` and `ytest` contain the complementary subset of rows. `XTRAIN` and `XTEST` contain the data taken from the columns of `X` that correspond to the current candidate feature set.

Each time it is called, `fun` must return a scalar value `criterion`. Typically, `fun` uses `XTRAIN` and `ytrain` to train or fit a model, then predicts values for `XTEST` using that model, and finally returns some measure of distance, or *loss*, of those predicted values from `ytest`. In the cross-validation calculation for a given candidate feature set, `sequentialfs` sums the values returned by `fun` and divides that sum

sequentialfs

by the total number of test observations. It then uses that mean value to evaluate each candidate feature subset.

Typical loss measures include sum of squared errors for regression models (`sequentialfs` computes the mean-squared error in this case), and the number of misclassified observations for classification models (`sequentialfs` computes the misclassification rate in this case).

Note `sequentialfs` divides the sum of the values returned by `fun` across all test sets by the total number of test observations. Accordingly, `fun` should not divide its output value by the number of test observations.

After computing the mean criterion values for each candidate feature subset, `sequentialfs` chooses the candidate feature subset that minimizes the mean criterion value. This process continues until adding more features does not decrease the criterion.

`inmodel = sequentialfs(fun,X,Y,Z,...)` allows any number of input variables `X`, `Y`, `Z`, `sequentialfs` chooses features (columns) only from `X`, but otherwise imposes no interpretation on `X`, `Y`, `Z`, All data inputs, whether column vectors or matrices, must have the same number of rows. `sequentialfs` calls `fun` with training and test subsets of `X`, `Y`, `Z`, ... as follows:

```
criterion = fun(XTRAIN,YTRAIN,ZTRAIN,...,  
               XTEST,YTEST,ZTEST,...)
```

`sequentialfs` creates `XTRAIN`, `YTRAIN`, `ZTRAIN`, ... , `XTEST`, `YTEST`, `ZTEST`, ... by selecting subsets of the rows of `X`, `Y`, `Z`, `fun` must return a scalar value `criterion`, but may compute that value in any way. Elements of the logical vector `inmodel` correspond to columns of `X` and indicate which features are finally chosen.

`[inmodel,history] = sequentialfs(fun,X,...)` returns information on which feature is chosen at each step. `history` is a scalar structure with the following fields:

- **Crit** — A vector containing the criterion values computed at each step.
- **In** — A logical matrix in which row *i* indicates the features selected at step *i*.

`[] = sequentialfs(...,param1,val1,param2,val2,...)` specifies optional parameter name/value pairs from the following table.

Parameter	Value
'cv'	<p>The validation method used to compute the criterion for each candidate feature subset.</p> <ul style="list-style-type: none"> • When the value is a positive integer <i>k</i>, <code>sequentialfs</code> uses <i>k</i>-fold cross-validation without stratification. • When the value is an object of the <code>cvpartition</code> class, other forms of cross-validation can be specified. • When the value is 'resubstitution', the original data are passed to <code>fun</code> as both the training and test data to compute the criterion. • When the value is 'none', <code>sequentialfs</code> calls <code>fun</code> as <code>criterion = fun(X,Y,Z,...)</code>, without separating test and training sets. <p>The default value is 10, that is, 10-fold cross-validation without stratification.</p> <p>So-called <i>wrapper methods</i> use a function <code>fun</code> that implements a learning algorithm. These methods usually apply cross-validation to select features. So-called <i>filter methods</i> use a function</p>

sequentialfs

Parameter	Value
	fun that measures characteristics of the data (such as correlation) to select features.
'mcreps'	A positive integer indicating the number of Monte-Carlo repetitions for cross-validation. The default value is 1. The value must be 1 if the value of 'cv' is 'resubstitution' or 'none'.
'direction'	The direction of the sequential search. The default is 'forward'. A value of 'backward' specifies an initial candidate set including all features and an algorithm that removes features sequentially until the criterion increases.
'keepin'	A logical vector or a vector of column numbers specifying features that must be included. The default is empty.
'keepout'	A logical vector or a vector of column numbers specifying features that must be excluded. The default is empty.
'nfeatures'	The number of features at which <code>sequentialfs</code> should stop. <code>inmodel</code> includes exactly this many features. The default value is empty, indicating that <code>sequentialfs</code> should stop when a local minimum of the criterion is found. A nonempty value overrides values of 'MaxIter' and 'TolFun' in 'options'.
'nullmodel'	A logical value, indicating whether or not the null model (containing no features from X) should be included in feature selection and in the history output. The default is false.

Parameter	Value
'options'	<p>Options structure for the iterative sequential search algorithm, as created by <code>statset</code>. <code>sequentialfs</code> uses the following <code>statset</code> parameters:</p> <ul style="list-style-type: none"> • <code>Display</code> — Amount of information displayed by the algorithm. The default is 'off'. • <code>MaxIter</code> — Maximum number of iterations allowed. The default is <code>Inf</code>. • <code>TolFun</code> — Termination tolerance for the objective function value. The default is <code>1e-6</code> if 'direction' is 'forward'; <code>0</code> if 'direction' is 'backward'. • <code>TolTypeFun</code> — Use absolute or relative objective function tolerances. The default is 'rel'. • <code>UseParallel</code> — Set to 'always' to compute in parallel. Default is 'never'. • <code>UseSubstreams</code> — Set to 'always' to compute in parallel in a reproducible fashion. Default is 'never'. To compute reproducibly, set <code>Streams</code> to a type allowing substreams: 'mlfg6331_64' or 'mrg32k3a'. • <code>Streams</code> — A <code>RandStream</code> object or cell array consisting of one such object. If you do not specify <code>Streams</code>, <code>sequentialfs</code> uses the default stream.

Examples

Perform sequential feature selection for classification of noisy features:

```
load fisheriris;
X = randn(150,10);
```

sequentialfs

```
X(:,[1 3 5 7])= meas;
y = species;

c = cvpartition(y,'k',10);
opts = statset('display','iter');
fun = @(XT,yT,Xt,yt)...
      (sum(~strcmp(yt,classify(Xt,XT,yT,'quadratic'))));

[fs,history] = sequentialfs(fun,X,y,'cv',c,'options',opts)
```

```
Start forward sequential feature selection:
Initial columns included: none
Columns that can not be included: none
Step 1, added column 7, criterion value 0.04
Step 2, added column 5, criterion value 0.0266667
Final columns included: 5 7
```

```
fs =
    0  0  0  0  1  0  1  0  0  0
history =
    In: [2x10 logical]
    Crit: [0.0400 0.0267]
```

```
history.In
ans =
    0  0  0  0  0  0  1  0  0  0
    0  0  0  0  1  0  1  0  0  0
```

See Also

[crossval](#) | [cvpartition](#) | [stepwisefit](#) | [statset](#)

Tutorials

- “Example: Sequential Feature Selection” on page 10-24

How To

- “Sequential Feature Selection” on page 10-23

Purpose Set and display properties

Syntax

```
set(A)
set(A,PropertyName)
A = set(A,PropertyName,PropertyValue,...)
B = set(A,PropertyName,value)
```

Description

`set(A)` displays all properties of the dataset array `A` and their possible values.

`set(A,PropertyName)` displays possible values for the property specified by the string `PropertyName`.

`A = set(A,PropertyName,PropertyValue,...)` sets property name/value pairs.

`B = set(A,PropertyName,value)` returns a dataset array `B` that is a copy of `A`, but with the property 'PropertyName' set to the value `value`.

Note Using `set(A,'PropertyName',value)` without assigning to a variable does not modify `A`'s properties. Use `A = set(A,'PropertyName',value)` to modify `A`.

Examples Create a dataset array from Fisher's iris data and add a description:

```
load fisheriris
NumObs = size(meas,1);
NameObs = strcat({'Obs'},num2str((1:NumObs)', '%-d'));
iris = dataset({nominal(species), 'species'},...
              {meas, 'SL', 'SW', 'PL', 'PW'},...
              'ObsNames', NameObs);
iris = set(iris, 'Description', 'Fisher''s Iris Data');
get(iris)
Description: 'Fisher's Iris Data'
Units: {}
DimNames: {'Observations' 'Variables'}
```

dataset.set

```
UserData: []  
ObsNames: {150x1 cell}  
VarNames: {'species' 'SL' 'SW' 'PL' 'PW'}
```

See Also

[get](#) | [summary](#)

Purpose Set default value for predict

Syntax B = setDefaultYfit(B,Yfit)

Description B = setDefaultYfit(B,Yfit) sets the default prediction for ensemble B to Yfit. The default prediction must be a character variable for classification or a numeric scalar for regression. This setting controls what predicted value CompactTreeBagger returns when no prediction is possible, for example when the predict method needs to predict for an observation which has only false values in the matrix supplied through 'useifort' argument.

See Also predict | TreeBagger.DefaultYfit

categorical.setdiff

Purpose

Set difference for categorical arrays

Note In a future release, the behavior of `categorical.setdiff` will change to be consistent with the MATLAB function `setdiff`. This behavior change is optional in R2012a. For a demonstration of using the 'R2012a' flag to preview the future behavior, or the 'legacy' flag to preserve the current behavior in your existing code, see the documentation for `setdiff`.

Syntax

```
C = setdiff(A,B)
[C,IA] = setdiff(A,B)
[...] = setdiff(A,B,'rows')
[...] = setdiff(...,'R2012a')
[...] = setdiff(...,'legacy')
[...] = setdiff(A,B,setOrder)
[...] = setdiff(A,B,'rows',setOrder)
```

Description

`C = setdiff(A,B)` for categorical vectors `A` and `B`, returns a categorical vector `C` containing the values in `A` that are not in `B` with no repetitions. The result `C` is sorted. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs.

`[C,IA] = setdiff(A,B)` also returns an index vector `IA` such that `C = A(IA)`. If there are repeated values in `A` that are not in `B`, then the index of the last occurrence of each repeated value is returned.

`[...] = setdiff(A,B,'rows')` for categorical matrices `A` and `B` with the same number of columns, returns the rows from `A` that are not in `B`. The rows of the matrix `C` are sorted. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs. The optional output `IA` is an index vector such that `C = C(IA,:)`.

`[...] = setdiff(...,'R2012a')` adopts the future behavior of `setdiff`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `B`, or `'rows'`.

`[...] = setdiff(..., 'legacy')` preserves the current behavior of `setdiff`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `B`, or `'rows'`.

`[...] = setdiff(A,B,setOrder)` and `[...] = setdiff(A,B, 'rows', setOrder)` returns the observations of `C` in a specific order. `setOrder='sorted'` returns the values or rows of `C` in sorted order. `setOrder='stable'` returns the values or rows of `C` in the same order as `A`. If `A` is a row vector, then `C` is also a row vector. Otherwise, `C` is a column vector. If `A` is a column vector. If there are repeated values in `A` that are not in `B`, then the index of the first occurrence of each repeated value is returned.

See Also

`intersect` | `ismember` | `setxor` | `union` | `unique`

dataset.setdiff

Purpose Set difference for dataset array observations

Syntax

```
C = setdiff(A,B)
C = setdiff(A,B,vars)
C = setxor(A,B,vars,setOrder)
[C,iA] = setxor( ___ )
```

Description

`C = setdiff(A,B)` for dataset arrays `A` and `B` returns the set of observations that are in `A` but not `B`, with repetitions removed. The observations in the dataset array `C` are sorted.

`C = setdiff(A,B,vars)` returns the set of observations that are in `A` but not `B`, considering only the variables specified in `vars`, with repetitions removed. The observations in the dataset array `C` are sorted by these variables. The values for variables not specified in `vars` for each observation in `C` are taken from the corresponding observation in `A`. If there are multiple observations in `A` that correspond to an observation in `C`, those values are taken from the first occurrence.

`C = setxor(A,B,vars,setOrder)` returns the observations in `C` in the order specified by `setOrder`.

`[C,iA] = setxor(___)` also returns the index vector `iA` such that `C = A(iA,:)`. If there are repeated observations in `A`, then `setxor` returns the index of the first occurrence. You can use any of the previous input arguments.

Input Arguments

A,B

Input dataset arrays.

vars

Cell array of strings containing variable names or a vector of integers containing variable column numbers, indicating the variables that `setdiff` considers.

Specify `vars` as `[]` to use its default value of all variables.

setOrder

Flag indicating the sorting order for the observations in **C**. The possible values of `setOrder` are:

'sorted'	Observations in C are in sorted order (default).
'stable'	Observations in C are in the same order that they appear in A .

Output Arguments

C

Dataset array with the observations that are in **A** but not **B**, with repetitions removed. **C** is in sorted order (by default), or the order specified by `setOrder`.

iA

Index vector, indicating the observations from **A** that are in **C**. The vector **iA** contains the index to the first occurrence of any repeated observations in **A**.

Examples

Set Difference of Two Dataset Arrays

Create a scalar structure array, and then convert it into two dataset arrays.

```
S(1,1).Name = 'CLARK';
S(1,1).Gender = 'M';
S(1,1).SystolicBP = 124;
S(1,1).DiastolicBP = 93;
```

```
S(2,1).Name = 'BROWN';
S(2,1).Gender = 'F';
S(2,1).SystolicBP = 122;
S(2,1).DiastolicBP = 80;
```

```
S(3,1).Name = 'MARTIN';
S(3,1).Gender = 'M';
S(3,1).SystolicBP = 130;
```

dataset.setdiff

```
S(3,1).DiastolicBP = 92;
```

```
A = struct2dataset(S(1:2));
```

```
B = struct2dataset(S(2:3));
```

The intersection of A and B is the second observation, with last name BROWN.

Return the set difference of A and B.

```
[C,iA] = setdiff(A,B)
```

```
C =
```

Name	Gender	SystolicBP	DiastolicBP
'CLARK'	'M'	124	93

```
iA =
```

```
1
```

The first observation in A is not present in B.

See Also

`dataset` | `intersect` | `ismember` | `setxor` | `sortrows` | `union` | `unique` |

Concepts

- “Dataset Arrays” on page 2-156

Purpose

Label levels

Syntax

```
A = setlabels(A,labels)
A = setlabels(A,labels,levels)
```

Description

`A = setlabels(A,labels)` labels the levels in the categorical array `A` using the cell array of strings or 2-D character matrix `labels`. Labels are assigned in the order given in `labels`.

`A = setlabels(A,labels,levels)` labels only the levels specified in the cell array of strings or 2-D character matrix `levels`.

Examples

Example 1

Relabel the species in Fisher's iris data using new categories:

```
load fisheriris
species = nominal(species);
species = mergelevels(...
    species,{'setosa','virginica'},'parent');
species = setlabels(species,'hybrid','versicolor');
getlabels(species)
ans =
    'hybrid'    'parent'
```

Example 2

- 1 Load patient data from the CSV file `hospital.dat` and store the information in a dataset array with observation names given by the first column in the data (patient identification):

```
patients = dataset('file','hospital.dat',...
    'delimiter',';',...
    'ReadObsNames',true);
```

- 2 Make the {0,1}-valued variable `smoke` nominal, and change the labels to 'No' and 'Yes':

```
patients.smoke = nominal(patients.smoke,{'No','Yes'});
```

categorical.setlabels

- 3 Add new levels to `smoke` as placeholders for more detailed histories of smokers:

```
patients.smoke = addlevels(patients.smoke,...
                           {'0-5 Years', '5-10 Years', 'LongTerm'});
```

- 4 Assuming the nonsmokers have never smoked, relabel the 'No' level:

```
patients.smoke = setlabels(patients.smoke, 'Never', 'No');
```

- 5 Drop the undifferentiated 'Yes' level from `smoke`:

```
patients.smoke = droplevels(patients.smoke, 'Yes');
```

Warning: `OLDLEVELS` contains categorical levels that were present in `A`, caused some array elements to have undefined levels.

Note that smokers now have an undefined level.

- 6 Set each smoker to one of the new levels, by observation name:

```
patients.smoke('YPL-320') = '5-10 Years';
```

See Also

`getlabels`

Purpose Set exclusive-or for categorical arrays

Note In a future release, the behavior of `categorical.setxor` will change to be consistent with the MATLAB function `setxor`. This behavior change is optional in R2012a. For a demonstration of using the 'R2012a' flag to preview the future behavior, or the 'legacy' flag to preserve the current behavior in your existing code, see the documentation for `setxor`.

Syntax

```
C = setxor(A,B)
[C,IA,IB] = setxor(A,B)
[...] = setxor(A,B,'rows')
[...] = setxor(...,'R2012a')
[...] = setxor(...,'legacy')
[...] = setxor(A,B,setOrder)
[...] = setxor(A,B,'rows',setOrder)
```

Description `C = setxor(A,B)` for categorical vectors `A` and `B`, returns a categorical vector `C` containing the values not in the intersection of `A` and `B` with no repetitions. The result `C` is sorted. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs.

`[C,IA,IB] = setxor(A,B)` also returns index vectors `IA` and `IB` such that `C` is a sorted combination of the values `A(IA)` and `B(IB)`. If there are repeated values that are not in the intersection in `A` or `B` then the index of the last occurrence of each repeated value is returned.

`[...] = setxor(A,B,'rows')` for categorical matrices `A` and `B` with the same number of columns, returns the rows that are not in the intersection of `A` and `B`. The rows of the matrix `C` are sorted. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs. The optional outputs `IA` and `IB` are index vectors such that `C` is the sorted combination of rows `A(IA,:)` and `B(IB,:)`.

categorical.setxor

`[...] = setxor(..., 'R2012a')` adopts the future behavior of `setxor`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `B`, or `'rows'`.

`[...] = setxor(..., 'legacy')` preserves the current behavior of `setxor`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `B`, or `'rows'`.

`[...] = setxor(A,B,setOrder)` and `[...] = setxor(A,B, 'rows', setOrder)` returns the observations of `C` in a specific order. `setOrder='sorted'` returns the values or rows of `C` in sorted order. `setOrder='stable'` returns the values or rows of `C` in the same order as `A`. If `A` and `B` are row vectors, then `C` is also a row vector. Otherwise, `C` is a column vector. `IA` and `IB` are column vectors. If there are repeated values that are not in the intersection of `A` and `B`, then the index of the first occurrence of each repeated value is returned.

See Also

`intersect` | `ismember` | `setdiff` | `union` | `unique`

Purpose	Set exclusive or for dataset array observations
Syntax	<pre>C = setxor(A,B) C = setxor(A,B,vars) C = setxor(A,B,vars,setOrder) [C,iA,iB] = setxor(___)</pre>
Description	<p><code>C = setxor(A,B)</code> for dataset arrays <code>A</code> and <code>B</code> returns the set of observations that are not in the intersection of the two arrays, with repetitions removed. The observations in the dataset array <code>C</code> are sorted.</p> <p><code>C = setxor(A,B,vars)</code> returns the set of observations that are not in the intersection of the two arrays, considering only the variables specified in <code>vars</code>, with repetitions removed. The observations in the dataset array <code>C</code> are sorted by these variables. The values for variables not specified in <code>vars</code> for each observation in <code>C</code> are taken from the corresponding observation in <code>A</code> or <code>B</code>. If there are multiple observations in <code>A</code> or <code>B</code> that correspond to an observation in <code>C</code>, those values are taken from the first occurrence.</p> <p><code>C = setxor(A,B,vars,setOrder)</code> returns the observations in <code>C</code> in the order specified by <code>setOrder</code>.</p> <p><code>[C,iA,iB] = setxor(___)</code> also returns index vectors <code>iA</code> and <code>iB</code> such that <code>C</code> is a sorted combination of the values <code>A(iA,:)</code> and <code>B(iB,:)</code>. If there are repeated observations in <code>A</code> or <code>B</code>, then <code>setxor</code> returns the index of the first occurrence. You can use any of the previous input arguments.</p>
Input Arguments	<p>A,B Input dataset arrays.</p> <p>vars Cell array of strings containing variable names or a vector of integers containing variable column numbers, indicating the variables in <code>A</code> and <code>B</code> that <code>setxor</code> considers.</p> <p>Specify <code>vars</code> as <code>[]</code> to use its default value of all variables.</p>

setOrder

Flag indicating the sorting order for the observations in **C**. The possible values of `setOrder` are:

'sorted'	Observations in C are in sorted order (default).
'stable'	Observations in C are in the same order that they appear in A , then B .

Output Arguments

C

Dataset array with the observations not in the intersection of **A** and **B**, with repetitions removed. **C** is in sorted order (by default), or the order specified by `setOrder`.

iA

Index vector, indicating the observations from **A** that are in **C**. The vector `iA` contains the index to the first occurrence of any repeated observations in **A**.

iB

Index vector, indicating the observations from **B** that are in **C**. The vector `iB` contains the index to the first occurrence of any repeated observations in **B**.

Examples

Symmetric Difference of Two Dataset Arrays

Create a scalar structure array, and then convert it into two dataset arrays.

```
S(1,1).Name = 'CLARK';  
S(1,1).Gender = 'M';  
S(1,1).SystolicBP = 124;  
S(1,1).DiastolicBP = 93;  
  
S(2,1).Name = 'BROWN';
```

```

S(2,1).Gender = 'F';
S(2,1).SystolicBP = 122;
S(2,1).DiastolicBP = 80;

S(3,1).Name = 'MARTIN';
S(3,1).Gender = 'M';
S(3,1).SystolicBP = 130;
S(3,1).DiastolicBP = 92;

A = struct2dataset(S(1:2));
B = struct2dataset(S(2:3));

```

The intersection of A and B is the second observation, with last name BROWN.

Return the symmetric difference of A and B.

```

[C,iA,iB] = setxor(A,B);
C

```

C =

Name	Gender	SystolicBP	DiastolicBP
'CLARK'	'M'	124	93
'MARTIN'	'M'	130	92

```

[iA iB]

```

ans =

```

     1     2

```

The symmetric difference contains the first observation from A, and the second observation from B.

See Also

dataset | intersect | ismember | setdiff | sortrows | union | unique |

Concepts

- “Dataset Arrays” on page 2-156

gmdistribution.SharedCov property

Purpose

true if all covariance matrices are restricted to be the same

Description

Logical true if all the covariance matrices are restricted to be the same (pooled estimate); logical false otherwise.

categorical.shiftdim

Purpose Shift dimensions of categorical array

Syntax `B = shiftdim(A,n)`
`[B,nshifts] = shiftdim(A)`

Description `B = shiftdim(A,n)` shifts the dimensions of the categorical array `A` by `N`. When `n` is positive, `shiftdim` shifts the dimensions to the left and wraps the `n` leading dimensions to the end. When `n` is negative, `shiftdim` shifts the dimensions to the right and pads with singletons.

`[B,nshifts] = shiftdim(A)` returns the array `B` with the same number of elements as `A` but with any leading singleton dimensions removed. `nshifts` returns the number of dimensions that are removed. If `A` is a scalar, `shiftdim` has no effect.

See Also `circshift` | `reshape` | `squeeze`

Purpose Prune ensemble

Syntax
`cmp = shrink(ens)`
`cmp = shrink(ens,Name,Value)`

Description `cmp = shrink(ens)` returns a compact shrunken version of `ens`, a regularized ensemble. `cmp` retains only learners with weights above a threshold.

`cmp = shrink(ens,Name,Value)` returns an ensemble with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

ens

A regression ensemble created with `fitensemble`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

lambda

Vector of nonnegative regularization parameter values for lasso. If `ens.Regularization` is nonempty (populate it with `regularize`), `shrink` regularizes `ens` using `lambda`. If `ens` contains a `Regularization` structure, you cannot pass `lambda`.

Default: []

threshold

RegressionEnsemble.shrink

Lower cutoff on weights for weak learners, a numeric nonnegative scalar. `shrink` creates `cmp` from those learners with weights above threshold.

Default: 0

weightcolumn

Column index of `ens.Regularization.TrainedWeights`, a positive integer. `shrink` creates `cmp` with learner weights from this column.

Default: 1

Output Arguments

cmp

A regression ensemble of class `CompactRegressionEnsemble`. Use `cmp` for making predictions exactly as you use `ens`, with the `predict` method.

`shrink` orders the members of `cmp` from largest to smallest.

Examples

Shrink a 300-member bagged regression ensemble using 0.1 for the parameter `lambda`, and view the number of members of the resulting ensemble:

```
X = rand(2000,20);
Y = repmat(-1,2000,1);
Y(sum(X(:,1:5),2)>2.5) = 1;
bag = fitensemble(X,Y,'Bag',300,'Tree','type','regression');
cmp = shrink(bag,'lambda',0.1);
cmp.NTrained
```

```
ans =
    83
```

See Also

`regularize` | `cvshrink` | `predict`

Tutorials

- “Ensemble Regularization” on page 13-98

gmdistribution.Sigma property

Purpose Input array of covariances

Description Input array of covariances SIGMA.

Purpose

Wilcoxon signed rank test

Syntax

```
p = signrank(x)
p = signrank(x,y)
p = signrank(x,y,Name,Value)
[p,h] = signrank( __ )
[p,h,stats] = signrank( __ )

[ __ ] = signrank(x,m)
[ __ ] = signrank(x,m,Name,Value)
```

Description

`p = signrank(x)` returns the p -value of a two-sided Wilcoxon signed rank test.

`signrank` tests the null hypothesis that data in the vector `x` come from a distribution whose median is zero at the 5% significance level. The test assumes that the data in `x` come from a continuous distribution symmetric about its median.

`p = signrank(x,y)` returns the p -value of a paired, two-sided test for the null hypothesis that $x - y$ comes from a distribution with zero median.

`p = signrank(x,y,Name,Value)` returns the p -value for the sign test with additional options specified by one or more `Name,Value` pair arguments.

`[p,h] = signrank(__)` also returns a logical value indicating the test decision. $h = 1$ indicates a rejection of the null hypothesis, and $h = 0$ indicates a failure to reject the null hypothesis at the 5% significance level. You can use any of the input arguments in the previous syntaxes.

`[p,h,stats] = signrank(__)` also returns the structure `stats` with information about the test statistic.

[___] = `signrank(x,m)` returns any of the output arguments in the previous syntaxes for the null hypothesis that the data in `x` are observations from a distribution with median `m`.

[___] = `signrank(x,m,Name,Value)` returns any of the output arguments in the previous syntaxes for the signed rank test with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

x - Sample data

vector

Sample data, specified as a vector.

Data Types

single | double

y - Sample data

vector

Sample data, specified as a vector. `y` must be the same length as `x`.

Data Types

single | double

m - Hypothesized value of the median

scalar

Hypothesized value of the median, specified as a scalar.

Example: `signrank(x,10)`

Data Types

single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: 'alpha',0.01,'method','approximate','tail','right'
 specifies a right-tailed signed rank test with 1% significance level,
 which returns the approximate p-value.

alpha - Significance level

0.05 (default) | scalar value in the range 0 to 1

Significance level of the decision of a hypothesis test, specified as the comma-separated pair consisting of 'alpha' and a scalar value in the range 0 to 1. Significance level of h is 100 * alpha%.

Example: 'alpha', 0.01

Data Types

double | single

method - Computation method of p

'exact' | 'approximate'

Computation method of p, specified as the comma-separated pair consisting of 'method' and one of the following.

'exact'	Exact computation of the <i>p</i> -value, <i>p</i> . Default value for 15 or fewer observations in <i>x</i> , <i>x</i> – <i>m</i> , or <i>x</i> – <i>y</i> when <i>method</i> is unspecified.
'approximate'	Normal approximation while computing the <i>p</i> -value, <i>p</i> . Default value for more than 15 observations in <i>x</i> , <i>x</i> – <i>m</i> , or <i>x</i> – <i>y</i> when 'method' is unspecified because the exact method can be slow on large samples.

Example: 'method','exact'

Data Types

char

tail - Type of test

'both' (default) | 'right' | 'left'

Type of test, specified as the comma-separated pair consisting of 'tail' and one of the following:

'both'	Two-sided hypothesis test, which is the default test type. <ul style="list-style-type: none">• For a one-sample test, the alternate hypothesis states that the data in x come from a continuous distribution with median different than 0 or m.• For a two-sample test, the alternate hypothesis states that the data in $x - y$ come from a distribution with median different than 0.
'right'	Right-tailed hypothesis test. <ul style="list-style-type: none">• For a one-sample test, the alternate hypothesis states that the data in x come from a continuous distribution with median greater than 0 or m.• For a two-sample test, the alternate hypothesis states the data in $x - y$ come from a distribution with median greater than 0.
'left'	Left-tailed hypothesis test. <ul style="list-style-type: none">• For a one-sample test, the alternate hypothesis states that the data in x come from a continuous distribution with median less than 0 or m.• For a two-sample test, the alternate hypothesis states the data in $x - y$ come from a distribution with median less than 0.

Example: 'tail','left'

Output Arguments

p - *p*-value of the test

nonnegative scalar

p-value of the test, returned as a nonnegative scalar from 0 to 1. *p* is the probability of observing a test statistic as or more extreme than the observed value under the null hypothesis. `signrank` computes the two-sided *p*-value by doubling the most significant one-sided value.

h - Result of the hypothesis test

1 | 0

Result of the hypothesis test, returned as a logical value.

- If $h = 1$, this indicates the rejection of the null hypothesis at the $100 * \alpha\%$ significance level.
- If $h = 0$, this indicates a failure to reject the null hypothesis at the $100 * \alpha\%$ significance level.

stats - Test statistics

structure

Test statistics, returned as a structure. The test statistics stored in `stats` are:

- `signrank`: Value of the sign rank test statistic.
- `zval`: Value of the z - statistic (computed when 'method' is 'approximate').

Examples**Test for Zero Median of a Single Population**

Test the hypothesis of zero median.

Generate the sample data.

```
rng('default') % for reproducibility
x = randn(1,25) + 1.30;
```

Test the hypothesis that the data in `x` has zero median.

```
[p,h] = signrank(x)
```

```
p =
```

```
3.2229e-05
```

```
h =
```

1

At the default 5% significance level, the value $h = 1$ indicates that the test rejects the null hypothesis of zero median.

Test the Median of Differences of Paired Samples

Test the hypothesis of zero median for the difference between paired samples.

Generate the sample data.

```
rng('default') % for reproducibility
x = lognrnd(2, .25, 10, 1);
y = x + trnd(2, 10, 1);
```

Test the hypothesis that $x - y$ has zero median.

```
[p,h] = signrank(x,y)
```

```
p =
    0.3223
```

```
h =
    0
```

The results indicate that the test fails to reject the null hypothesis of zero median in the difference at the default 5% significance level.

Signed Rank Test for Large Samples

Conduct a -sided test on a large sample using approximation.

Navigate to a folder containing sample data.

```
cd(matlabroot)
cd('help/toolbox/stats/examples')
```

Load the sample data.

```
load gradespaired
```

Test the null hypothesis that the median of the grade differences of students before and after participating in a tutoring program is 0 against the alternate that it is less than 0.

```
[p,h,stats] = signrank(gradespaired(:,1),gradespaired(:,2),'tail','left')
```

```
p =
```

```
    0.0047
```

```
h =
```

```
    1
```

```
stats =
```

```
    zval: -2.5982
```

```
    signedrank: 2.0175e+03
```

Because the sample size is greater than 15, signrank uses an approximate method to calculate the p -value and also returns the value of the z -statistic. The value $h = 1$ indicates that the test rejects the null hypothesis that there is no difference between the grade medians at the 5% significance level. There is enough statistical evidence to conclude that the median grade before the tutoring program is less than the median grade after the tutoring program.

Repeat the test using the exact method.

```
[p,h,stats] = signrank(gradespaired(:,1),gradespaired(:,2),...  
'tail','left','method','exact')
```

```
p =
```

```
0.0045
```

```
h =
```

```
1
```

```
stats =
```

```
signedrank: 2.0175e+03
```

The results obtained using the approximate method are consistent with the exact method.

Two-Sided Test for the Median of a Single Population

Load the sample data.

```
load mileage
```

The data contains the mileages per gallon for three different types of cars in columns 1 to 3.

Test the hypothesis that the median mileage for the type of cars in the second column differs from 33.

```
[p,h,stats] = signrank(mileage(:,2),33)
```

```
p =
```

```
0.0313
```

```
h =
```

```
1
```

```
stats =
```

```
signedrank: 21
```

At the 5% significance level, the results indicate that the median mileage for the second type of cars differs from 33. Note that `signrank` uses an exact method to calculate the p -value for small samples and does not return the z -statistic.

Right-Sided Test for the Median of a Single Population

Use the name-value pair arguments in `signrank`.

Load the sample data.

```
load mileage
```

The data contains the mileage per gallon for three different types of cars in columns 1 to 3.

Test the hypothesis that the median mileage for the type of cars in the second row are larger than 33.

```
[p,h,stats] = signrank(mileage(:,2),33,'tail','right')
```

```
p =  
    0.0156
```

```
h =  
    1
```

```
stats =  
    signedrank: 21
```

Repeat the same test at the 1% significance level using the approximate method.

```
[p,h,stats] = signrank(mileage(:,2),33,'tail','right','alpha',0.01,...  
    'method','approximate')
```

```
p =  
    0.0180
```

```
h =  
  
0  
  
stats =  
  
      zval: 2.0966  
      signedrank: 21
```

This result, $h = 0$, indicates that the null hypothesis cannot be rejected at the 1% significance level.

Definitions

Wilcoxon Signed Rank Test

The Wilcoxon signed rank test is a nonparametric test for two populations when the observations are paired. In this case, the test statistic, W , is the sum of the ranks of positive differences between the observations in the two samples (that is, $x - y$). When you use the test for one sample, then W is the sum of the ranks of positive differences between the observations and the hypothesized median value M_0 (which is 0 when you use `signrank(x)` and m when you use `signrank(x, m)`).

z-Statistic

For large samples, or when `method` is `approximate`, the `signrank` function calculates the p -value using the z -statistic, given by

$$z = \frac{(W - n(n+1)/4)}{\sqrt{\frac{n(n+1)(2n+1) - \text{tieadj}}{24}}},$$

where n is the sample size of the difference $x - y$ or $x - m$. For the two-sample case, `signrank` uses `[tie_rank, tieadj] = tiedrank(abs(diffxy), 0, 0, epsdiff)` to obtain the tie adjustment value `tieadj`.

Algorithms

signrank treats NaNs in x and y as missing values and ignores them.

For the two-sample case, signrank uses a tolerance based on the values $\text{epsdiff} = \text{eps}(x) + \text{eps}(y)$. The signrank function treats any pair of values with difference $d(i) = x(i) - y(i)$ that differ by no more than the sum of their two eps values ($\text{abs}(d(i)) < \text{epsdiff}(i)$) as ties.

References

[1] Gibbons, J. D., and S. Chakraborti. *Nonparametric Statistical Inference*, 5th Ed., Boca Raton, FL: Chapman & Hall/CRC Press, Taylor & Francis Group, 2011.

[2] Hollander, M., and D. A. Wolfe. *Nonparametric Statistical Methods*. Hoboken, NJ: John Wiley & Sons, Inc., 1999.

See Also

ranksum | signtest | ttest | ztest

signtest

Purpose

Sign test

Syntax

```
p = signtest(x)
p = signtest(x,y)
p = signtest(x,y,Name,Value)
[p,h] = signtest( __ )
[p,h,stats] = signtest( __ )
```

```
[ __ ] = signtest(x,m)
[ __ ] = signtest(x,m,Name,Value)
```

Description

`p = signtest(x)` returns the p -value for a two-sided sign test.

`signtest` tests the hypothesis that data in `x` has a continuous distribution with zero median against the alternative that the distribution does not have zero median at the 5% significance level.

`p = signtest(x,y)` returns the p -value of a two-sided sign test. Here, `signtest` tests for the hypothesis that the data in `x - y` has a distribution with zero median against the alternative that the distribution does not have zero median. Note that a hypothesis of zero median for `x - y` is not equivalent to a hypothesis of equal median for `x` and `y`.

`p = signtest(x,y,Name,Value)` returns the p -value for the sign test with additional options specified by one or more `Name,Value` pair arguments.

`[p,h] = signtest(__)` also returns a logical value indicating the test decision. The value `h = 1` indicates a rejection of the null hypothesis, and `h = 0` indicates a failure to reject the null hypothesis at the 5% significance level. You can use any of the input arguments in the previous syntaxes.

`[p,h,stats] = signtest(__)` also returns the structure `stats` containing information about the test statistic.

`[__] = signtest(x,m)` returns any of the output arguments in the previous syntaxes for the test whether the data in `x` are observations from a distribution with median `m` against the alternative that the median is different from `m`.

`[__] = signtest(x,m,Name,Value)` returns any of the output arguments in the previous syntaxes for the sign test with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

x - Sample data

vector

Sample data, specified as a vector.

Data Types

single | double

y - Sample data

vector

Sample data, specified as a vector. `y` must be the same length as `x`.

Data Types

single | double

m - Hypothesized value of the median

scalar

Hypothesized value of the median, specified as a scalar.

Example: `signtest(x,35)`

Data Types

single | double

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'alpha',0.01,'method','approximate','tail','right'` specifies a right-tailed sign test with 1% significance level, which returns the approximate *p*-value.

alpha - Significance level

0.05 (default) | scalar value in the range 0 to 1

Significance level of the hypothesis test, specified as the comma-separated pair consisting of `'alpha'` and a scalar value in the range 0 to 1. The default value of `alpha` is 0.05. Significance level of *h* is $100 * \text{alpha}\%$.

Example: `'alpha',0.01`

Data Types

double | single

method - *p*-value computation method

`'exact'` | `'approximate'`

p-value computation method, specified as the comma-separated pair consisting of `'method'` and one of the following:

<code>'exact'</code>	Exact computation of the <i>p</i> -value, <i>p</i> .
<code>'approximate'</code>	Normal approximation for computing the <i>p</i> -value, <i>p</i> .

The default computation method is `'exact'`, if there are fewer than 100 observations and `'approximate'` if there are 100 observations or more.

Example: `'method','exact'`

Data Types

char

tail - Type of test`'both' (default) | 'right' | 'left'`

Type of test, specified as the comma-separated pair consisting of 'tail' and one of the following:

'both'	<p>Two-sided hypothesis test, which is the default test type.</p> <ul style="list-style-type: none"> • For a one-sample test, the alternate hypothesis states that the data in x come from a continuous distribution with median different than zero (or m). • For a two-sample test, the alternate hypothesis states that the data in $x - y$ come from a distribution with median different than zero.
'right'	<p>Right-tailed hypothesis test.</p> <ul style="list-style-type: none"> • For a one-sample test, the alternate hypothesis states that the data in x come from a continuous distribution with median greater than zero (or m). • For a two-sample test, the alternate hypothesis states the data in $x - y$ come from a distribution with median greater than zero.
'left'	<p>Left-tailed hypothesis test.</p> <ul style="list-style-type: none"> • For a one-sample test, the alternate hypothesis states that the data in x come from a continuous distribution with median less than zero (or m). • For a two-sample test, the alternative hypothesis states the data in $x - y$ come from a distribution with median less than zero.

Example: `'tail','left'`

signtest

Output Arguments

p - *p*-value of the test

nonnegative scalar

p-value of the test, returned as a nonnegative scalar from 0 to 1. *p* is the probability of observing a test statistic as or more extreme than the observed value under the null hypothesis. `signtest` computes the two-sided *p*-value by doubling the most significant one-sided value.

h - Result of the hypothesis test

1 | 0

Result of the hypothesis test, returned as a logical value.

- If $h = 1$, this indicates rejection of the null hypothesis at the $100 * \alpha\%$ significance level.
- If $h = 0$, this indicates a failure to reject the null hypothesis at the $100 * \alpha\%$ significance level.

stats - Test statistics

structure

Test statistics, returned as a structure. The test statistics stored in `stats` are:

- `sign`: Value of the sign test statistic.
- `zval`: Value of the z-statistic (computed only for large samples).

Examples

Test for Zero Median of a Single Population

Test the hypothesis of zero median.

Generate the sample data.

```
rng('default') % for reproducibility  
x = randn(1,25);
```

The sampling distribution of *x* is symmetric with zero median.

Test the null hypothesis that *x* comes from a distribution with a median different from zero median.

```
[p,h,stats] = signtest(x,0)

p =
    0.1078

h =
    0

stats =
    zval: NaN
    sign: 17
```

At the default 5% significance level, the result $h = 0$ indicates that `signtest` fails to reject to the null hypothesis of zero median. `signtest` calculates the p -value using the exact method, hence it does not calculate `zval` and returns it as a NaN.

Test for Zero Median for the Difference of Paired Samples

Test the hypothesis of zero median for the difference between paired samples.

Generate the sample data.

```
rng('default') % for reproducibility
before = lognrnd(2, .25, 10, 1);
after = before + (lognrnd(0, .5, 10, 1) - 1);
```

The sampling distribution of the difference between `before` and `after` is symmetric with zero median.

Test the null hypothesis that the difference of `before` and `after` has zero median.

```
[p,h] = signtest(before,after)

p =

    0.7539
```

signtest

```
h =
```

```
0
```

At the default 5% significance level, the value $h = 0$ indicates that `signtest` fails to reject to the null hypothesis of zero median in the difference.

Medians of Paired Samples

Test the hypothesis of zero median for the difference between two paired samples using the exact and approximate methods.

Generate the sample data.

```
rng('default') % for reproducibility
x = lognrnd(2,.25,15,1);
y = x + trnd(2,15,1);
display([x y])
```

```
ans =
```

```
8.4521    7.8047
11.6869   11.4094
4.2009    5.1133
9.1664   12.1655
8.0020   10.0300
5.3285    6.0153
6.6300    5.1235
8.0499    8.6737
18.0763   19.2164
14.7665   15.3380
5.2726    8.4187
15.7798   16.2093
8.8583    8.5575
7.2735    7.4783
```

```
8.8347 7.8894
```

Test the hypothesis that $x - y$ has zero median.

```
[p,h,stats] = signtest(x,y)
```

```
p =
```

```
0.3018
```

```
h =
```

```
0
```

```
stats =
```

```
zval: NaN
```

```
sign: 5
```

At the default 5% significance level, the value $h = 0$ indicates that the test fails to reject the null hypothesis of zero median in the difference.

Repeat the test using the approximate method.

```
[p,h,stats] = signtest(x,y,'method','approximate')
```

```
p =
```

```
0.3017
```

```
h =
```

```
0
```

signtest

```
stats =  
  
    zval: -1.0328  
    sign: 5
```

The approximate p -value, which `signtest` obtains using the z -statistic, is really close to the exact p -value.

Test for Large Samples

Perform a left-sided sign test for large samples.

Navigate to a folder containing sample data.

```
cd(matlabroot)  
cd('help/toolbox/stats/examples')
```

Load the sample data.

```
load gradespaired
```

Test the null hypothesis that the median of the grade differences before and after the tutoring program is 0 against the alternate that it is less than 0.

```
[p,h,stats] = signtest(gradespaired(:,1),gradespaired(:,2),'tail','left')
```

```
p =  
  
    0.0013
```

```
h =  
  
    1
```

```
stats =
```



```
zval: -3.0110
sign: 37
```

Because the sample size is large (greater than 100), `signtest` uses an approximate method to calculate the p -value and also returns the value of the z -statistic. The test rejects the null hypothesis that there is no difference between the grade medians at the 5% significance level.

Test for Median of a Single Population

Test the hypothesis that the population median is different from a specified value.

Load the sample data.

```
load lawdata
```

The data set has 15 observations for variables `gpa` and `lsat`.

Test the hypothesis that the median `lsat` score is higher than 570.

```
[p,h,stats] = signtest(lsat,570,'tail','right')
```

```
p =
```

```
0.0176
```

```
h =
```

```
1
```

```
stats =
```

```
zval: NaN
```

```
sign: 12
```

Both the p -value, 0.0176, and $h = 1$ indicate that at the 5% significance level the test concludes in favor of the alternate hypothesis.

Definitions

Sign Test

The sign test is a nonparametric test for the median of a population or median of the difference of two populations. For example, for tests on a single population median:

- If the test is two-sided, then the test statistic, S , is the minimum of the number of observations that are smaller or larger than the hypothesized median value, M_0 .
- If the test is right-sided, then S is the number of observations that are larger than the hypothesized median value M_0 .
- If the test is left-sided, then S is the number of observations that are smaller than the hypothesized median value M_0 .

z-Statistic

For a large sample, `signtest` uses the z -statistic to approximate the p -value. The `signtest` test statistic is the number of elements that are greater than 0 (for `signtest(x)` or `signtest(x-y)`), or m (for `signtest(x,m)`). Hence, the z -statistic of the sign test, with the continuity correction, is:

$$z = \frac{(S - E(S))}{\sqrt{V(S)}} = \frac{(S - (0.5)n - 0.5\text{sign}(npos - nneg))}{\sqrt{(0.5)(0.5)n}},$$

where $npos$ and $nneg$ are the number of positive and negative differences from the hypothesized median value, respectively.

Algorithms

For a one-sample test, `signtest` omits values in x that are zero or NaN.

For a two-sample test, `signtest` omits values in $x - y$ that are zero or NaN.

References

[1] Gibbons, J. D., and S. Chakraborti. *Nonparametric Statistical Inference*, 5th Ed. Boca Raton, FL: Chapman & Hall/CRC Press, Taylor & Francis Group, 2011.

[2] Hollander, M., and D. A. Wolfe. *Nonparametric Statistical Methods*. Hoboken, NJ: John Wiley & Sons, Inc., 1999.

See Also

ranksum | signrank | ttest | ztest

silhouette

Purpose Silhouette plot

Syntax

```
silhouette(X,clust)
s = silhouette(X,clust)
[s,h] = silhouette(X,clust)
[...] = silhouette(X,clust,metric)
[...] = silhouette(X,clust,distfun,p1,p2,...)
```

Description `silhouette(X,clust)` plots cluster silhouettes for the n -by- p data matrix X , with clusters defined by `clust`. Rows of X correspond to points, columns correspond to coordinates. `clust` can be a categorical variable, numeric vector, character matrix, or cell array of strings containing a cluster name for each point. `silhouette` treats NaNs or empty strings in `clust` as missing values, and ignores the corresponding rows of X . By default, `silhouette` uses the squared Euclidean distance between points in X .

`s = silhouette(X,clust)` returns the silhouette values in the n -by-1 vector `s`, but does not plot the cluster silhouettes.

`[s,h] = silhouette(X,clust)` plots the silhouettes, and returns the silhouette values in the n -by-1 vector `s`, and the figure handle in `h`.

`[...] = silhouette(X,clust,metric)` plots the silhouettes using the inter-point distance function specified in `metric`. Choices for `metric` are given in the following table.

Metric	Description
'Euclidean'	Euclidean distance
'sqEuclidean'	Squared Euclidean distance (default)
'cityblock'	Sum of absolute differences
'cosine'	One minus the cosine of the included angle between points (treated as vectors)
'correlation'	One minus the sample correlation between points (treated as sequences of values)

Metric	Description
'Hamming'	Percentage of coordinates that differ
'Jaccard'	Percentage of nonzero coordinates that differ
Vector	A numeric distance matrix in upper triangular vector form, such as is created by <code>pdist</code> . <code>X</code> is not used in this case, and can safely be set to <code>[]</code> .

For more information on each metric, see “Distance Metrics” on page 13-9.

`[...] = silhouette(X,clust,distfun,p1,p2,...)` accepts a function handle `distfun` to a metric of the form

$$d = \text{distfun}(X0,X,p1,p2,\dots)$$

where `X0` is a 1-by-`p` point, `X` is an `n`-by-`p` matrix of points, and `p1`, `p2`, ... are optional additional arguments. The function `distfun` returns an `n`-by-1 vector `d` of distances between `X0` and each point (row) in `X`. The arguments `p1`, `p2`, ... are passed directly to the function `distfun`.

Definitions

Silhouette Value

The silhouette value for each point is a measure of how similar that point is to points in its own cluster compared to points in other clusters, and ranges from -1 to +1.

The silhouette value for the i th point, S_i , is defined as

$$S_i = (b_i - a_i) / \max(a_i, b_i)$$

where a_i is the average distance from the i th point to the other points in the same cluster as i , and b_i is the minimum average distance from the i th point to points in a different cluster, minimized over clusters.

Examples

```
X = [randn(10,2)+ones(10,2);
randn(10,2)-ones(10,2)];
cidx = kmeans(X,2,'distance','sqeuclid');
s = silhouette(X,cidx,'sqeuclid');
```

References

[1] Kaufman L., and P. J. Rousseeuw. *Finding Groups in Data: An Introduction to Cluster Analysis*. Hoboken, NJ: John Wiley & Sons, Inc., 1990.

See Also

dendrogram | kmeans | linkage | pdist

How To

- “Grouping Variables” on page 2-72

Purpose Convert categorical array to single array

Syntax `B = single(A)`

Description `B = single(A)` converts the categorical array `A` to a single array. Each element of `B` contains the internal categorical level code for the corresponding element of `A`.

See Also `double`

dataset.single

Purpose Convert dataset variables to single array

Syntax `B = single(A)`
`B = single(A,vars)`

Description `B = single(A)` returns the contents of the dataset A, converted to one single array. The classes of the variables in the dataset must support the conversion.

`B = single(A,vars)` returns the contents of the dataset variables specified by vars. vars is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector.

See Also `dataset` | `double` | `replacedata`

Purpose Size of categorical array

Syntax

```
d = size(A)
[m,n] = size(A)
[m1,m2,m3,...,mn] = size(A)
m = size(A,dim)
```

Description `d = size(A)` returns the two-element row vector `d = [m,n]` containing the number of rows and columns in the matrix for an `m`-by-`n` categorical matrix `A`. For `n`-D categorical arrays, `size(A)` returns a 1-by-`n` vector of dimension lengths. Trailing singleton dimensions are ignored.

`[m,n] = size(A)` for a categorical matrix `A`, returns the number of rows and columns in `A` as separate output variables.

`[m1,m2,m3,...,mn] = size(A)`, for `n > 1`, returns the sizes of the first `n` dimensions of the categorical array `A`. If the number of output arguments `n` does not equal `ndims(A)`, then for:

`n > ndims(A)` `size` returns ones in the "extra" variables, i.e., outputs `ndims(A)+1` through `n`.

`n < ndims(A)` `mn` contains the product of the sizes of dimensions `n` through `ndims(A)`.

`m = size(A,dim)` returns the length of the dimension specified by the scalar `dim`. For example, `size(A,1)` returns the number of rows. If `dim > ndims(A)`, `m` will be 1.

See Also `length` | `ndims` | `numel`

dataset.size

Purpose Size of dataset array

Syntax
D = SIZE(A)
[NOBS,NVARS] = SIZE(A)
[M1,M2,M3,...,MN] = SIZE(A)
M = size(A,dim)

Description D = SIZE(A) returns the two-element row vector D = [NOBS,NVARS] containing the number of observations and number of variables in the dataset A. A dataset array always has two dimensions.

[NOBS,NVARS] = SIZE(A) returns the numbers of observations and variables in the dataset A as separate output variables.

[M1,M2,M3,...,MN] = SIZE(A), for N > 2, returns M1 = NOBS, M2 = NVARS, and M3,...,MN = 1.

M = size(A,dim) returns the length of the dimension specified by the scalar dim:

- M = size(A,1) returns NOBS
- M = size(A,2) returns NVARS
- M = size(A,k) returns 1 for k > 2

See Also length | ndims | numel

Purpose Number of dimensions in matrix

Syntax

```
d = size(p)
[m,n] = size(p)
m = size(p,dim)
```

Description `d = size(p)` returns the two-element row vector `d = [m,n]` containing the number of points in the point set and the number of dimensions the points are in, for the point set `p`. These correspond to the number of rows and columns in the matrix that would be produced by the expression `p(:,:)`.

`[m,n] = size(p)` returns the number of points and dimensions for `p` as separate output variables.

`m = size(p,dim)` returns the length of the dimension specified by the scalar `dim`. For example, `size(p,1)` returns the number of rows (points in the point set). If `dim` is greater than 2, `m` will be 1.

Examples The commands

```
P = sobolset(12);
d = size(P)
```

return

```
d = [9.0072e+015 12]
```

The command

```
[m,n] = size(P)
```

returns

```
m = 9.0072e+015
n = 12
```

The command

grandset.size

```
m2 = size(P, 2)
```

returns

```
m2 = 12
```

See Also

[length](#) | [ndims](#) | [grandset](#)

Purpose	Slice sampler
Syntax	<pre>rnd = slicesample(initial,nsamples,'pdf',pdf) rnd = slicesample(initial,nsamples,'logpdf',logpdf) [rnd,neval] = slicesample(initial,...) [rnd,neval] = slicesample(initial,...,Name,Value)</pre>
Description	<p><code>rnd = slicesample(initial,nsamples,'pdf',pdf)</code> generates <code>nsamples</code> random samples using the slice sampling method (see “Algorithms” on page 20-2295). <code>pdf</code> gives the target probability density function (<code>pdf</code>). <code>initial</code> is a row vector or scalar containing the initial value of the random sample sequences.</p> <p><code>rnd = slicesample(initial,nsamples,'logpdf',logpdf)</code> generates samples using the logarithm of the <code>pdf</code>.</p> <p><code>[rnd,neval] = slicesample(initial,...)</code> returns the average number of function evaluations that occurred in the slice sampling.</p> <p><code>[rnd,neval] = slicesample(initial,...,Name,Value)</code> generates random samples with additional options specified by one or more <code>Name,Value</code> pair arguments.</p>
Tips	<ul style="list-style-type: none">• There are no definitive suggestions for choosing appropriate values for <code>burnin</code>, <code>thin</code>, or <code>width</code>. Choose starting values of <code>burnin</code> and <code>thin</code>, and increase them, if necessary, to give the requisite independence and marginal distributions. See Neal [1] for details of the effect of adjusting <code>width</code>.
Input Arguments	<p>initial Initial point, a scalar or row vector. Set <code>initial</code> so <code>pdf(initial)</code> is a strictly positive scalar. <code>length(initial)</code> is the number of dimensions of each sample.</p> <p>nsamples Positive integer, the number of samples that <code>slicesample</code> generates.</p>

pdf

Handle to a function that generates the probability density function, specified with @. pdf can be unnormalized, meaning it need not integrate to 1.

logpdf

Handle to a function that generates the logarithm of the probability density function, specified with @. logpdf can be the logarithm of an unnormalized pdf.

Name-Value Pair Arguments

Specify optional comma-separated pairs of **Name**, **Value** arguments, where **Name** is the argument name and **Value** is the corresponding value. **Name** must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as **Name1**, **Value1**, ..., **NameN**, **ValueN**.

burnin

Nonnegative integer, the number of samples to generate and discard before generating the samples to return. The slice sampling algorithm is a Markov chain whose stationary distribution is proportional to that of the pdf argument. Set **burnin** to a high enough value that you believe the Markov chain approximately reaches stationarity after **burnin** samples.

Default: 0

thin

Positive integer, where **slicesample** discards every **thin** - 1 samples and returns the next. The slice sampling algorithm is a Markov chain, so the samples are serially correlated. To reduce the serial correlation, choose a larger value of **thin**.

Default: 1

width

Width of the interval around the current sample, a scalar or vector of positive values. `slicesample` begins with this interval and searches for an appropriate region containing the points of `pdf` that evaluate to a large enough value.

- If `width` is a scalar and the samples have multiple dimensions, `slicesample` uses `width` for each dimension.
- If `width` is a vector, it should have the same length as `initial`.

Default: 10

Output Arguments**rnd**

`nsamples-by-length(initial)` matrix, where each row is one sample.

neval

Scalar, the mean number of function evaluations per sample. `neval` includes the `burnin` and `thin` evaluations, not just the evaluations of samples returned in `rnd`. Therefore the total number of function evaluations is

$$\text{neval} * (\text{nsamples} * \text{thin} + \text{burnin}).$$
Examples

Generate random samples from a multimodal density using `slicesample`.

- 1 Define a function proportional to a multimodal density:

```
f = @(x) exp(-x.^2/2).*(1 + (sin(3*x)).^2).*...
    (1 + (cos(5*x).^2));
area = quad(f, -5, 5);
```

- 2 Generate 2000 samples from the density, using a burn-in period of 1000, and keeping one in five samples:

```
N = 2000;
```

slicesample

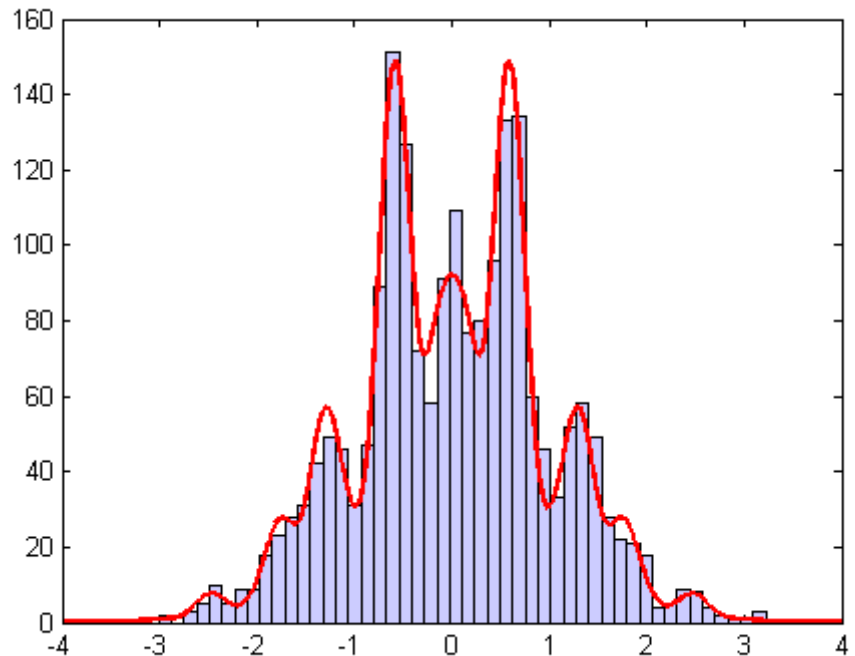
```
x = slicesample(1,N,'pdf',f,'thin',5,'burnin',1000);
```

- 3** Plot a histogram of the sample:

```
[binheight,bincenter] = hist(x,50);  
h = bar(bincenter,binheight,'hist');  
set(h,'facecolor',[0.8 .8 1]);
```

- 4** Scale the density to have the same area as the histogram, and superimpose it on the histogram:

```
hold on  
xd = get(gca,'XLim');  
xgrid = linspace(xd(1),xd(2),1000);  
binwidth = (bincenter(2)-bincenter(1));  
y = (N*binwidth/area) * f(xgrid);  
plot(xgrid,y,'r','LineWidth',2)  
hold off
```

The samples seem to fit the theoretical distribution well, so the burnin value seems adequate.

Algorithms

At each point in the sequence of random samples, `slicesample` selects the next point by “slicing” the density to form a neighborhood around the previous point where the density is above some value. Consequently, the sample points are not independent. Nearby points in the sequence tend to be closer together than they would be from a sample of independent values. For many purposes, the entire set of points can be used as a sample from the target distribution. However, when this type of serial correlation is a problem, the `burnin` and `thin` parameters can help reduce that correlation.

slicesample

`slicesample` uses the slice sampling algorithm of Neal [1]. For numerical stability, it converts a `pdf` function into a `logpdf` function. The algorithm to resize the support region for each level, called “stepping-out” and “stepping-in,” was suggested by Neal.

References

[1] Neal, Radford M. *Slice Sampling*. Ann. Stat. Vol. 31, No. 3, pp. 705–767, 2003. Available at Project Euclid.

See Also

`mhsample` | `rand` | `randsample`

Purpose

Skewness

Syntax

```
y = skewness(X)
y = skewness(X, flag)
y = skewness(X, flag, dim)
```

Description

`y = skewness(X)` returns the sample skewness of `X`. For vectors, `skewness(x)` is the skewness of the elements of `x`. For matrices, `skewness(X)` is a row vector containing the sample skewness of each column. For `N`-dimensional arrays, `skewness` operates along the first nonsingleton dimension of `X`.

`y = skewness(X, flag)` specifies whether to correct for bias (`flag = 0`) or not (`flag = 1`, the default). When `X` represents a sample from a population, the skewness of `X` is biased; that is, it will tend to differ from the population skewness by a systematic amount that depends on the size of the sample. You can set `flag = 0` to correct for this systematic bias.

`y = skewness(X, flag, dim)` takes the skewness along dimension `dim` of `X`.

`skewness` treats NaNs as missing values and removes them.

Algorithms

Skewness is a measure of the asymmetry of the data around the sample mean. If skewness is negative, the data are spread out more to the left of the mean than to the right. If skewness is positive, the data are spread out more to the right. The skewness of the normal distribution (or any perfectly symmetric distribution) is zero.

The skewness of a distribution is defined as

$$s = \frac{E(x - \mu)^3}{\sigma^3}$$

where μ is the mean of x , σ is the standard deviation of x , and $E(t)$ represents the expected value of the quantity t . `skewness` computes a sample version of this population value.

skewness

When you set `flag` to 1, the following equation applies:

$$s_1 = \frac{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^3}{\left(\sqrt{\frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2} \right)^3}$$

When you set `flag` to 0, the following equation applies:

$$s_0 = \frac{\sqrt{n(n-1)}}{n-2} s_1$$

This bias-corrected formula requires that `X` contain at least three elements.

Examples

```
X = randn([5 4])
X =
    1.1650    1.6961   -1.4462   -0.3600
    0.6268    0.0591   -0.7012   -0.1356
    0.0751    1.7971    1.2460   -1.3493
    0.3516    0.2641   -0.6390   -1.2704
   -0.6965    0.8717    0.5774    0.9846

y = skewness(X)
y =
   -0.2933    0.0482    0.2735    0.4641
```

See Also

[kurtosis](#) | [mean](#) | [moment](#) | [std](#) | [var](#)

Purpose

Number of initial points to omit from sequence

Description

The Skip property of a point set contains a positive integer which specifies the number of initial points in the sequence to omit from the point set. The default Skip value is 0.

Initial points of a sequence sometimes exhibit undesirable properties, for example the first point is often $(0,0,0,\dots)$ and this may "unbalance" the sequence since its counterpart, $(1,1,1,\dots)$, never appears. Another common reason is that initial points often exhibit correlations among different dimensions which disappear later in the sequence.

Examples

Examine the difference between skipping and not skipping points:

```
% No skipping produces the standard Sobol sequence.  
P = sobolset(5);  
P(1:3,:)
```

```
% Skip the first point of the sequence. The point set now  
% starts at the second point of the basic Sobol sequence.  
P.Skip = 1;  
P(1:3,:)
```

See Also

[Leap](#) | [net](#) | [grandset](#) | [subsref](#)

Dimensions	Number of dimensions
Leap	Interval between points
ScrambleMethod	Settings that control scrambling
Skip	Number of initial points to omit from sequence
Type	Name of sequence on which point set P is based

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

References

- [1] Bratley, P., and B. L. Fox, "ALGORITHM 659 Implementing Sobol's Quasirandom Sequence Generator," *ACM Transactions on Mathematical Software*, Vol. 14, No. 1, pp. 88-100, 1988.
- [2] Joe, S., and F. Y. Kuo, "Remark on Algorithm 659: Implementing Sobol's Quasirandom Sequence Generator," *ACM Transactions on Mathematical Software*, Vol. 29, No. 1, pp. 49-57, 2003.
- [3] Hong, H. S., and F. J. Hickernell, "ALGORITHM 823: Implementing Scrambled Digital Sequences," *ACM Transactions on Mathematical Software*, Vol. 29, No. 2, pp. 95-109, 2003.
- [4] Matousek, J., "On the L2-discrepancy for anchored boxes," *Journal of Complexity*, Vol. 14, pp. 527-556, 1998.

See Also

haltonset

How To

- "Quasi-Random Point Sets" on page 6-16

sobolset

Purpose Construct Sobol quasi-random point set

Syntax
`p = sobolset(d)`
`p = sobolset(d,prop1,va11,prop2,va12,...)`

Description
`p = sobolset(d)` constructs a d -dimensional point set `p` of the `sobolset` class, with default property settings.
`p = sobolset(d,prop1,va11,prop2,va12,...)` specifies property name/value pairs used to construct `p`.

The object `p` returned by `sobolset` encapsulates properties of a specified quasi-random sequence. The point set is finite, with a length determined by the `Skip` and `Leap` properties and by limits on the size of point set indices (maximum value of 2^{53}). Values of the point set are not generated and stored in memory until you access `p` using `net` or parenthesis indexing.

Examples Generate a 3-D Sobol point set, skip the first 1000 values, and then retain every 101st point:

```
p = sobolset(3,'Skip',1e3,'Leap',1e2)
p =
    Sobol point set in 3 dimensions (8.918019e+013 points)
    Properties:
        Skip : 1000
        Leap : 100
    ScrambleMethod : none
        PointOrder : standard
```

Use `scramble` to apply a random linear scramble combined with a random digital shift:

```
p = scramble(p,'MatousekAffineOwen')
p =
    Sobol point set in 3 dimensions (8.918019e+013 points)
    Properties:
        Skip : 1000
```



```
Leap : 100
ScrambleMethod : MatousekAffineOwen
PointOrder : standard
```

Use net to generate the first four points:

```
X0 = net(p,4)
X0 =
    0.7601    0.5919    0.9529
    0.1795    0.0856    0.0491
    0.5488    0.0785    0.8483
    0.3882    0.8771    0.8755
```

Use parenthesis indexing to generate every third point, up to the 11th point:

```
X = p(1:3:11,:)
X =
    0.7601    0.5919    0.9529
    0.3882    0.8771    0.8755
    0.6905    0.4951    0.8464
    0.1955    0.5679    0.3192
```

References

- [1] Bratley, P., and B. L. Fox. "Algorithm 659 Implementing Sobol's Quasirandom Sequence Generator." *ACM Transactions on Mathematical Software*. Vol. 14, No. 1, 1988, pp. 88–100.
- [2] Joe, S., and F. Y. Kuo. "Remark on Algorithm 659: Implementing Sobol's Quasirandom Sequence Generator." *ACM Transactions on Mathematical Software*. Vol. 29, No. 1, 2003, pp. 49–57.
- [3] Hong, H. S., and F. J. Hickernell. "Algorithm 823: Implementing Scrambled Digital Sequences." *ACM Transactions on Mathematical Software*. Vol. 29, No. 2, 2003, pp. 95–109.
- [4] Matousek, J. "On the L2-Discrepancy for Anchored Boxes." *Journal of Complexity*. Vol. 14, No. 4, 1998, pp. 527–556.

sobolset

See Also

haltonset | net | scramble

Purpose Sort elements of ordinal array

Syntax

```
B = sort(A)
B = sort(A,dim)
B = sort(A,dim,mode)
[B,I] = sort(A,...)
```

Description `B = sort(A)`, when `A` is an ordinal vector, sorts the elements of `A` in ascending order. For ordinal matrices, `sort(A)` sorts each column of `A` in ascending order. For N -D ordinal arrays, `sort(A)` sorts along the first nonsingleton dimension of `A`. `B` is an ordinal array with the same levels as `A`.

`B = sort(A,dim)` sorts `A` along dimension `dim`.

`B = sort(A,dim,mode)` sorts `A` in the order specified by `mode`. `mode` is 'ascend' for ascending order, or 'descend' for descending order.

`[B,I] = sort(A,...)` also returns an index matrix `I`. If `A` is a vector, then `B = A(I)`. If `A` is an m -by- n matrix and `dim` is 1, then `B(:,j) = A(I(:,j),j)` for `j = 1:n`.

Elements with undefined levels are sorted to the end.

Examples Sort the columns of an ordinal array in ascending order:

```
A = ordinal([6 2 5; 2 4 1; 3 2 4],...
            {'lo','med','hi'},[],[0 2 4 6])
```

```
A =
    hi      med      hi
    med     hi      lo
    med     med     hi
```

```
B = sort(A)
B =
    med     med     lo
    med     med     hi
    hi      hi      hi
```

ordinal.sort

See Also

`sortrows`

Purpose Sort rows of dataset array

Syntax

```
B = sortrows(A)
B = sortrows(A,vars)
B = sortrows(A,'obsnames')
B = sortrows(A,vars,mode)
[B,idx] = sortrows(A)
```

Description `B = sortrows(A)` returns a copy of the dataset array `A`, with the observations sorted in ascending order by all of the variables in `A`. The observations in `B` are sorted first by the first variable, next by the second variable, and so on. Each variable in `A` must be a valid input to `sort`, or, if a variable contains multiple columns, to the MATLAB `sortrows` function or the `sortrows` function for ordinal data.

`B = sortrows(A,vars)` sorts the observations in `A` by the variables specified by `vars`. `vars` is a positive integer, a vector of positive integers, variable names, a cell array containing one or more variable names, or a logical vector.

`B = sortrows(A,'obsnames')` sorts the observations in `A` by observation name.

`B = sortrows(A,vars,mode)` sorts in the direction specified by `mode`. When `mode` is the single string `'ascend'` (the default) or `'descend'`, `sortrows` sorts `A` by the variables specified by `vars` in ascending or descending order, respectively. `mode` can also be a cell array containing the strings `'ascend'` or `'descend'`, to specify a different sorting direction for each variable in `vars`. Specify `[]` for `vars` to sort using all variables.

`[B,idx] = sortrows(A)` also returns an index vector `idx` such that `B = A(idx,:)`.

Examples Sort the data in `hospital.mat` by age and then by last name:

```
load hospital
hospital(1:5,1:3)
ans =
```

dataset.sortrows

```
                LastName      Sex      Age
YPL-320      'SMITH'        Male      38
GLI-532      'JOHNSON'      Male      43
PNI-258      'WILLIAMS'      Female    38
MIJ-579      'JONES'          Female    40
XLK-030      'BROWN'          Female    49
```

```
hospital = sortrows(hospital,{'Age','LastName'});
hospital(1:5,1:3)
ans =
```

```
                LastName      Sex      Age
REV-997      'ALEXANDER'    Male      25
FZR-250      'HALL'          Male      25
LIM-480      'HILL'          Female    25
XUE-826      'JACKSON'       Male      25
SCQ-914      'JAMES'         Male      25
```

Sort the data in hospital by gender in ascending order, and age in descending order.

```
hospital = sortrows(hospital,{'Sex','Age'},{'ascend','descend'});
hospital(1:5,1:3)
ans =
```

```
                LastName      Sex      Age
XLK-030      'BROWN'          Female    49
GGU-691      'HUGHES'        Female    49
KKL-155      'ADAMS'         Female    48
HQO-561      'BRYANT'        Female    48
BKD-785      'CLARK'         Female    48
```

```
hospital(end-4:end,1:3)
ans =
```

```
                LastName      Sex      Age
VNL-702      'MOORE'         Male      28
REV-997      'ALEXANDER'    Male      25
```

FZR-250	'HALL'	Male	25
XUE-826	'JACKSON'	Male	25
SCQ-914	'JAMES'	Male	25

See Also

[dataset](#) | [sortrowsunique](#) |

Related Examples

- “Sort Observations in Dataset Arrays” on page 2-118

Concepts

- “Dataset Arrays” on page 2-156

ordinal.sortrows

Purpose Sort rows

Syntax

```
B = sortrows(A)
B = sortrows(A,col)
[B,I] = sortrows(A)
[B,I] = sortrows(A,col)
```

Description `B = sortrows(A)` sorts the rows of the 2-D ordinal matrix `A` in ascending order, as a group. `B` is an ordinal array with the same levels as `A`.

`B = sortrows(A,col)` sorts `A` based on the columns specified in the vector `col`. If an element of `col` is positive, the corresponding column in `A` is sorted in ascending order; if an element of `col` is negative, the corresponding column in `A` is sorted in descending order.

`[B,I] = sortrows(A)` and `[B,I] = sortrows(A,col)` also returns an index matrix `I` such that `B = A(I,:)`.

Elements with undefined levels are sorted to the end.

Examples Sort the rows of an ordinal array in ascending order for the first column, and then in descending order for the second column:

```
A = ordinal([6 2 5; 2 4 1; 3 2 4],...
            {'lo','med','hi'},[],[0 2 4 6])
```

```
A =
    hi     med     hi
    med    hi     lo
    med    med    hi
```

```
B = sortrows(A,[1 -2])
B =
    med    hi     lo
    med    med    hi
    hi     med    hi
```

See Also [sort](#) | [sortrows](#)

Purpose Format distance matrix

Syntax

```
Z = squareform(y)
y = squareform(Z)
Z = squareform(y, 'tovector')
Y = squareform(Z, 'tomatrix')
```

Description `Z = squareform(y)`, where `y` is a vector as created by the `pdist` function, converts `y` into a square, symmetric format `Z`, in which `Z(i, j)` denotes the distance between the `i`th and `j`th objects in the original data.

`y = squareform(Z)`, where `Z` is a square, symmetric matrix with zeros along the diagonal, creates a vector `y` containing the `Z` elements below the diagonal. `y` has the same format as the output from the `pdist` function.

`Z = squareform(y, 'tovector')` forces `squareform` to treat `y` as a vector.

`Y = squareform(Z, 'tomatrix')` forces `squareform` to treat `Z` as a matrix.

The last two formats are useful if the input has a single element, so that it is ambiguous whether the input is a vector or square matrix.

Examples

```
y = 1:6
y =
    1    2    3    4    5    6

X = [0 1 2 3; 1 0 4 5; 2 4 0 6; 3 5 6 0]
X =
    0    1    2    3
    1    0    4    5
    2    4    0    6
    3    5    6    0
```

Then `squareform(y) = X` and `squareform(X) = y`.

squareform

See Also

`pdist`

Purpose Squeeze singleton dimensions from categorical array

Syntax `B = squeeze(A)`

Description `B = squeeze(A)` returns an array B with the same elements as the categorical array A but with all the singleton dimensions removed. A singleton is a dimension such that `size(A,dim)=1`. 2-D arrays are unaffected by `squeeze` so that row vectors remain rows.

See Also `shiftdim`

Purpose Stack data from multiple variables into single variable

Syntax

```
tall = stack(wide,datavars)
[tall,iwide] = stack(wide,datavars)
tall = stack(wide,datavars,Parameter,value)
```

Description `tall = stack(wide,datavars)` converts a wide-format dataset array into a tall-format array, by stacking multiple variables in `wide` into a single variable in `tall`. In general, `tall` contains fewer variables but more observations than `wide`.

`datavars` specifies a group of `m` data variables in `wide`. `stack` creates a single data variable in `tall` by interleaving their values, and if `wide` has `n` observations, then `tall` has `m-by-n` observations. In other words, `stack` takes the `m` data values from each observation in `wide` and stacks them up to create `m` observations in `tall`. `datavars` is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector. `stack` also creates a grouping variable in `tall` to indicate which of the `m` data variables in `wide` each observation in `tall` corresponds to.

`stack` assigns values for the "per-variable properties (e.g., `Units` and `VarDescription`) for the new data variable in `tall` from the corresponding property values for the first variable listed in `datavars`.

`stack` copies the remaining variables from `wide` to `tall` without stacking, by replicating each of their values `m` times. These variables are typically grouping variables. Because their values are constant across each group of `m` observations in `tall`, they identify which observation in `wide` an observation in `tall` came from.

`[tall,iwide] = stack(wide,datavars)` returns an index vector `iwide` indicating the correspondence between observations in `tall` and those in `wide`. `stack` creates `tall(j,:)` using `wide(iwide(j),datavars)`.

For more information on grouping variables, see "Grouping Variables" on page 2-72.

Input Arguments

`tall = stack(wide,datavars,Parameter,value)` uses the following parameter name/value pairs to control how `stack` converts variables in `wide` to variables in `tall`:

'ConstVars '	Variables in <code>wide</code> to copy to <code>tall</code> without stacking. <code>ConstVars</code> is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector. The default is all variables in <code>wide</code> not specified in <code>datavars</code> .
'NewDataVarName '	A name for the data variable to be created in <code>tall</code> . The default is a concatenation of the names of the <code>m</code> variables that are stacked up.
'IndVarName '	A name for the grouping variable to create in <code>tall</code> to indicate the source of each value in the new data variable. The default is based on the 'NewDataVarName' parameter.

You can also specify multiple groups of data variables in `wide`, each of which becomes a variable in `tall`. All groups must contain the same number of variables. Use a cell array to contain multiple parameter values for `datavars`, and a cell array of strings to contain multiple 'NewDataVarName'.

Examples

Convert a wide format data set to tall format, and then back to a different wide format:

```
load flu
```

```
% FLU has a 'Date' variable, and 10 variables for estimated
% influenza rates (in 9 different regions, estimated from
```

```
% Google searches, plus a nationwide estimate from the
% CDC). Combine those 10 variables into a "tall" array that
% has a single data variable, 'FluRate', and an indicator
% variable, 'Region', that says which region each estimate
% is from.
[flu2,iflu] = stack(flu, 2:11, 'NewDataVarName','FluRate', ...
    'IndVarName','Region')

% The second observation in FLU is for 10/16/2005. Find the
% observations in FLU2 that correspond to that date.
flu(2,:)
flu2(iflu==2,:)

% Use the 'Date' variable from that tall array to split
% 'FluRate' into 52 separate variables, each containing the
% estimated influenza rates for each unique date. The new
% "wide" array has one observation for each region. In
% effect, this is the original array FLU "on its side".
dateNames = cellstr(datestr(flu.Date,'mmm_DD_YYYY'));
[flu3,iflu2] = unstack(flu2, 'FluRate', 'Date', ...
    'NewDataVarNames',dateNames)

% Since observations in FLU3 represent regions, IFLU2
% indicates the first occurrence in FLU2 of each region.
flu2(iflu2,:)
```

See Also

[dataset.unstack](#) | [dataset.join](#)

How To

- “Grouping Variables” on page 2-72

Purpose Current state of the stream

Description The State property of a quasi-random stream contains the index into the associated point set of the next point to draw in the stream. Getting and resetting the State property allows you to return a stream to a previous state. The initial value of State is 1.

Examples

```
Q = grandstream('sobol', 5);
s = Q.State;
u1 = grand(Q, 10)
Q.State = s;
u2 = grand(Q, 10) % contains exactly the same values as u1
```

See Also grand

statget

Purpose Access values in statistics options structure

Syntax
`val = statget(options,param)`
`val = statget(options,param,default)`

Description `val = statget(options,param)` returns the value of the parameter specified by the string `param` in the statistics options structure `options`. If the parameter is undefined in `options`, `statget` returns `[]`. You need to type only enough leading characters to define the parameter name uniquely. `statget` ignores case for parameter names. For available options, see Inputs.

`val = statget(options,param,default)` returns `default` if the specified parameter is undefined in the optimization options structure `options`.

Input Arguments

DerivStep

Relative difference used in finite difference derivative calculations. A positive scalar, or a vector of positive scalars the same size as the vector of parameters estimated by the Statistics Toolbox function using the options structure.

Display

Amount of information displayed by the algorithm.

- 'off' — Displays no information.
- 'final' — Displays the final output.
- 'iter' — Displays iterative output to the command window for some functions; otherwise displays the final output.

FunValCheck

Check for invalid values, such as NaN or Inf, from the objective function.

- 'off'
- 'on'

GradObj

Flags whether the objective function returns a gradient vector as a second output.

- 'off'
- 'on'

Jacobian

Flags whether the objective function returns a Jacobian as a second output.

- 'off'
- 'on'

MaxFunEvals

Maximum number of objective function evaluations allowed. Positive integer.

MaxIter

Maximum number of iterations allowed. Positive integer.

OutputFcn

The solver calls all output functions after each iteration.

- Function handle specified using @
- a cell array with function handles
- an empty array (default)

Robust

Invoke robust fitting option.

- 'off'
- 'on'

RobustWgtFun

A weight function for robust fitting. Valid only when `Robust` is 'on'. Can also be a function handle that accepts a normalized residual as input and returns the robust weights as output.

- 'bisquare'
- 'andrews'
- 'cauchy'
- 'fair'
- 'huber'
- 'logistic'
- 'talwar'
- 'welsch'

Streams

A single instance of the `RandStream` class, or a cell array of `RandStream` instances. The `Streams` option is accepted by some functions to govern what stream(s) to use in generating random numbers within the function. If 'UseSubstreams' is 'always', the `Streams` value must be a scalar, or must be empty. If 'UseParallel' is 'always' and 'UseSubstreams' is 'never', then the `Streams` argument must either be empty, or its length must match the number of processors used in the computation: equal to the `matlabpool` size if a `matlabpool` is open, a scalar otherwise.

TolBnd

Parameter bound tolerance. Positive scalar.

TolFun

Termination tolerance for the objective function value. Positive scalar.

TolTypeFun

Use TolFun for absolute or relative objective function tolerances.

- 'abs'
- 'rel'

TolTypeX

Use TolX for absolute or relative parameter tolerances.

- 'abs'
- 'rel'

TolX

Termination tolerance for the parameters. Positive scalar.

Tune

The tuning constant used in robust fitting to normalize the residuals before applying the weight function. The default value depends upon the weight function. This parameter is necessary if you specify the weight function as a function handle. Positive scalar.

UseParallel

Flag indicating whether eligible functions should use capabilities of the Parallel Computing Toolbox (PCT), if the capabilities are available. That is, if the PCT is installed, and a PCT matlabpool is in effect. Valid values are 'never' (the default), for serial computation, and 'always', for parallel computation.

UseSubstreams

Flag indicating whether the random number generator in eligible functions should use Substream property of the RandStream class. 'never' (default) or 'always'. 'always', high level iterations within the function will set the Substream property to the value of the iteration. This behavior helps to generate reproducible random number streams in parallel and/or serial mode computation.

WgtFun

A weight function for robust fitting. Valid only when Robust is 'on'. Can also be a function handle that accepts a normalized residual as input and returns the robust weights as output.

- 'bisquare'
- 'andrews'
- 'cauchy'
- 'fair'
- 'huber'
- 'logistic'
- 'talwar'
- 'welsch'

Examples

This statement returns the value of the Display statistics options parameter from the structure called my_options.

```
val = statget(my_options, 'Display')
```

Return the value of the Display statistics options parameter from the structure called my_options (as in the previous example). If the Display parameter is undefined, statget returns the value 'final'.

```
optnew = statget(my_options, 'Display', 'final');
```

See Also

statset

Purpose

Create statistics options structure

Syntax

```
statset
statset(statfun)
options = statset(...)
options = statset(fieldname1,val1,fieldname2,val2,...)
options = statset(oldopts,fieldname1,val1,fieldname2,val2,
    ...)
options = statset(oldopts,newopts)
```

Description

statset with no input arguments and no output arguments displays all fields of a statistics options structure and their possible values.

statset(statfun) displays fields and default values used by the Statistics Toolbox function statfun. Specify statfun using a string name or a function handle.

options = statset(...) creates a statistics options structure options. With no input arguments, all fields of the options structure are an empty array ([]). With a specified statfun, function-specific fields are default values and the remaining fields are []. Function-specific fields set to [] indicate that the function is to use its default value for that parameter. For available options, see Inputs.

options = statset(*fieldname1*,*val1*,*fieldname2*,*val2*,...) creates an options structure in which the named fields have the specified values. Any unspecified values are []. Use strings for field names. For fields that are string-valued, you must input the complete string for the value. If you provide an invalid string for a value, statset uses the default.

options = statset(*oldopts*,*fieldname1*,*val1*,*fieldname2*,*val2*,...) creates a copy of oldopts with the named parameters changed to the specified values.

options = statset(*oldopts*,*newopts*) combines an existing options structure, oldopts, with a new options structure, newopts. Any

parameters in `newopts` with nonempty values overwrite corresponding parameters in `oldopts`.

Input Arguments

DerivStep

Relative difference used in finite difference derivative calculations. A positive scalar, or a vector of positive scalars the same size as the vector of parameters estimated by the Statistics Toolbox function using the `options` structure.

Display

Amount of information displayed by the algorithm.

- 'off' — Displays no information.
- 'final' — Displays the final output.
- 'iter' — Displays iterative output to the command window for some functions; otherwise displays the final output.

FunValCheck

Check for invalid values, such as NaN or Inf, from the objective function.

- 'off'
- 'on'

GradObj

Flags whether the objective function returns a gradient vector as a second output.

- 'off'
- 'on'

Jacobian

Flags whether the objective function returns a Jacobian as a second output.

- 'off'
- 'on'

MaxFunEvals

Maximum number of objective function evaluations allowed. Positive integer.

MaxIter

Maximum number of iterations allowed. Positive integer.

OutputFcn

The solver calls all output functions after each iteration.

- Function handle specified using @
- a cell array with function handles
- an empty array (default)

Robust

Invoke robust fitting option.

- 'off'
- 'on'

Robust will be removed in a future software release. Use RobustWgtFun for robust fitting.

RobustWgtFun

Weight function for robust fitting. Can also be a function handle that accepts a normalized residual as input and returns the robust weights as output. If you use a function handle, give a Tune constant. See “Robust Options” on page 20-2328.

Streams

A single instance of the `RandStream` class, or a cell array of `RandStream` instances. The `Streams` option is accepted by some functions to govern what stream(s) to use in generating random numbers within the function. If `'UseSubstreams'` is `'always'`, the `Streams` value must be a scalar, or must be empty. If `'UseParallel'` is `'always'` and `'UseSubstreams'` is `'never'`, then the `Streams` argument must either be empty, or its length must match the number of processors used in the computation: equal to the `matlabpool` size if a `matlabpool` is open, a scalar otherwise.

TolBnd

Parameter bound tolerance. Positive scalar.

TolFun

Termination tolerance for the objective function value. Positive scalar.

TolTypeFun

Use `TolFun` for absolute or relative objective function tolerances.

- `'abs'`
- `'rel'`

TolTypeX

Use `TolX` for absolute or relative parameter tolerances.

- `'abs'`
- `'rel'`

TolX

Termination tolerance for the parameters. Positive scalar.

Tune

Tuning constant used in robust fitting to normalize the residuals before applying the weight function. The default value depends upon the

weight function. This parameter is necessary if you specify the weight function as a function handle. Positive scalar. See “Robust Options” on page 20-2328.

UseParallel

Flag indicating whether eligible functions should use capabilities of the Parallel Computing Toolbox (PCT), if the capabilities are available. That is, if the PCT is installed, and a PCT matlabpool is in effect. Valid values are 'never' (the default), for serial computation, and 'always', for parallel computation.

UseSubstreams

Flag indicating whether the random number generator in eligible functions should use Substream property of the RandStream class. 'never' (default) or 'always'. 'always', high level iterations within the function will set the Substream property to the value of the iteration. This behavior helps to generate reproducible random number streams in parallel and/or serial mode computation.

WgtFun

Weight function for robust fitting. Valid only when Robust is 'on'. Can also be a function handle that accepts a normalized residual as input and returns the robust weights as output. See “Robust Options” on page 20-2328.

WgtFun will be removed in a future software release. Use RobustWgtFun instead.

Definitions

Robust Options

Weight Function	Equation	Default Tuning Constant
'andrews'	$w = (\text{abs}(r) < \pi) .* \sin(r) ./ r$	1.339
'bisquare' (default)	$w = (\text{abs}(r) < 1) .* (1 - r.^2).^2$	4.685
'cauchy'	$w = 1 ./ (1 + r.^2)$	2.385
'fair'	$w = 1 ./ (1 + \text{abs}(r))$	1.400
'huber'	$w = 1 ./ \max(1, \text{abs}(r))$	1.345
'logistic'	$w = \tanh(r) ./ r$	1.205
'talwar'	$w = 1 * (\text{abs}(r) < 1)$	2.795
'welsch'	$w = \exp(-(r.^2))$	2.985
[]	No robust fitting	—

Examples

Suppose you want to change the default parameter values for the function `evfit`, which fits an extreme value distribution to data. The defaults parameter values are:

```
statset('evfit')
ans =
    Display: 'off'
  MaxFunEvals: []
    MaxIter: []
    TolBnd: []
    TolFun: []
  TolTypeFun: []
    TolX: 1.0000e-06
  TolTypeX: []
    GradObj: []
    Jacobian: []
```

```
DerivStep: []
FunValCheck: []
Robust: []
RobustWgtFun: []
WgtFun: []
Tune: []
UseParallel: []
UseSubstreams: []
Streams: []
OutputFcn: []
```

The only parameters that `evfit` uses are `Display` and `TolX`. To create an options structure with the value of `TolX` set to `1e-8`, enter:

```
options = statset('TolX',1e-8)
% Pass options to evfit:
mu = 1;
sigma = 1;
data = evrnd(mu,sigma,1,100);

paramhat = evfit(data,[],[],[],options)
```

See Also

`statget`

ProbDistUnivParam.std

Purpose Return standard deviation of ProbDistUnivParam object

Syntax $S = \text{std}(PD)$

Description $S = \text{std}(PD)$ returns S , the standard deviation of the ProbDistUnivParam object PD .

Input Arguments PD An object of the class ProbDistUnivParam.

Output Arguments S The standard deviation of the ProbDistUnivParam object PD .

See Also `std`

Purpose Improve generalized linear regression model by adding or removing terms

Syntax
`mdl1 = step(mdl)`
`mdl1 = step(mdl,Name,Value)`

Description `mdl1 = step(mdl)` returns an improved generalized linear model based on `mdl`, with one predictor added or removed.

`mdl1 = step(mdl,Name,Value)` improves a generalized linear model with additional options specified by one or more `Name,Value` pair arguments.

Tips

- Use `addTerms` or `removeTerms` to control exactly which terms enter or leave the model.

Input Arguments

mdl
Generalized linear model, as constructed by `GeneralizedLinearModel.fit` or `GeneralizedLinearModel.stepwise`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Criterion

Criterion that `step` uses in selecting terms to add or remove.

Criterion	PEnter	PRemove	Compared Against
'Deviance'	0.05	< 0.1	p -value for F or chi-square test
'SSE'	0.05	< 0.1	p -value for F test

GeneralizedLinearModel.step

Criterion	PEnter	PRemove	Compared Against
'AIC'	0	< 0.01	Change in AIC
'BIC'	0	< 0.01	Change in BIC
'Rsquared'	0.1	> 0.05	Increase in R-squared
'AdjRsquared'	0	> -0.05	Increase in adjusted R-squared

Default: 'deviance'

Lower

Model specification that describes the terms that must exist in the fit.

Default: 'constant'

NSteps

Maximum number of steps to take.

Default: 1

Penter

Improvement measure for adding a term.

- If Criterion = 'sse' or 'deviance', Penter is the value of p such that, if a term has a p -value less than p , then add the term to the model.
- For other values of Criterion, if the improvement in the criterion is more than Penter, then add the term to the model.

Default: 0.05 for Criterion = 'sse' or 'deviance'; 0 for other values of Criterion

PRemove

Improvement measure for removing a term.

- If `Criterion = 'sse'` or `'deviance'`, `PRemove` is the value of p such that, if a term has a p -value greater than p , then remove the term from the model.
- For other values of `Criterion`, if the improvement in the criterion is less than `Penter`, then remove the term from the model.

Default: 0.1 for `Criterion = 'sse'` or `'deviance'`; 0 for other values of `Criterion`

Upper

Model specification describing largest set of terms in the fit.

Default: `'interactions'`

Verbose

Integer from 0 to 2 controlling the display of information.

- 0 suppresses all display.
- 1 displays the action taken at each step.
- 2 also displays the actions evaluated at each step.

Default: 1

Output Arguments

`mdl1`

Linear model, the same as `mdl` but with additional terms given in terms. You can set `mdl1` equal to `mdl` to overwrite `mdl`.

Examples

Add Predictors One at a Time

Fit a Poisson regression model using random data and a single predictor, then step in other predictors.

GeneralizedLinearModel.step

Generate artificial data with 20 predictors, using three of the predictors for the responses.

```
rng('default') % for reproducibility
X = randn(100,20);
mu = exp(X(:,[5 10 15])*[.4;.2;.3] + 1);
y = poissrnd(mu);
```

Construct a generalized linear model using $X(:,1)$ as the only predictor.

```
mdl = GeneralizedLinearModel.fit(X,y,...
    'y ~ x1','Distribution','poisson')
```

```
mdl =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x1
Distribution = Poisson
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	1.1278	0.057487	19.618	1.0904e-85
x1	0.061287	0.04848	1.2642	0.20617

100 observations, 98 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 1.59, p-value = 0.208

Add a variable to the model using `step`.

```
mdl1 = step(mdl)
```

1. Adding x5, Deviance = 134.2976, Chi2Stat = 50.80176, PValue = 1.021821e-12

```
mdl1 =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x1 + x5
```


Distribution = Poisson

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	1.0418	0.062341	16.712	1.07e-62
x1	0.018803	0.049916	0.37671	0.70639
x5	0.47881	0.067875	7.0542	1.7357e-12

100 observations, 97 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 52.4, p-value = 4.21e-12

Add another variable to the model using step.

```
mdl1 = step(mdl1)
```

2. Adding x15, Deviance = 105.9973, Chi2Stat = 28.30027, PValue = 1.038814e-07

```
mdl1 =
```

Generalized Linear regression model:

```
log(y) ~ 1 + x1 + x5 + x15  
Distribution = Poisson
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	1.0459	0.0627	16.681	1.7975e-62
x1	0.026907	0.05003	0.53782	0.5907
x5	0.3983	0.068376	5.8251	5.7073e-09
x15	0.28949	0.053992	5.3618	8.2375e-08

100 observations, 96 error degrees of freedom

Dispersion: 1

Chi²-statistic vs. constant model: 80.7, p-value = 2.18e-17

Algorithms

Stepwise regression is a systematic method for adding and removing terms from a linear or generalized linear model based on their statistical

GeneralizedLinearModel.step

significance in explaining the response variable. The method begins with an initial model, specified using `modelspec`, and then compares the explanatory power of incrementally larger and smaller models.

MATLAB uses forward and backward stepwise regression to determine a final model. At each step, the method searches for terms to add to or remove from the model based on the value of the `'Criterion'` argument. The default value of `'Criterion'` is `'sse'`, and in this case, `LinearModel.stepwise` and `GeneralizedLinearModel.stepwise` use the p -value of an F-statistic to test models with and without a potential term at each step. If a term is not currently in the model, the null hypothesis is that the term would have a zero coefficient if added to the model. If there is sufficient evidence to reject the null hypothesis, the term is added to the model. Conversely, if a term is currently in the model, the null hypothesis is that the term has a zero coefficient. If there is insufficient evidence to reject the null hypothesis, the term is removed from the model.

Here is how stepwise proceeds when `'Criterion'` is `'sse'`:

- 1** Fit the initial model.
- 2** If any terms not in the model have p -values less than an entrance tolerance (that is, if it is unlikely that they would have zero coefficient if added to the model), add the one with the smallest p -value and repeat this step; otherwise, go to step 3.
- 3** If any terms in the model have p -values greater than an exit tolerance (that is, if it is unlikely that the hypothesis of a zero coefficient can be rejected), remove the one with the largest p -value and go to step 2; otherwise, end.

There are several other criteria available, which you can specify using the `'Criterion'` argument. You can use the change in the value of the Akaike information criterion, Bayesian information criterion, R-squared, adjusted R-squared, or deviance (only for `GeneralizedLinearModel.stepwise`) as a criterion to add or remove terms.

Depending on the terms included in the initial model and the order in which terms are moved in and out, the method may build different models from the same set of potential terms. The method terminates when no single step improves the model. There is no guarantee, however, that a different initial model or a different sequence of steps will not lead to a better fit. In this sense, stepwise models are locally optimal, but may not be globally optimal.

Alternatives

Use `GeneralizedLinearModel.stepwise` to select a model from a starting model, continuing until no single step is beneficial.

Use `addTerms` or `removeTerms` to add or remove particular terms.

See Also

`addTerms` | `GeneralizedLinearModel` | `removeTerms` | `GeneralizedLinearModel.stepwise` |

Related Examples

- “Plots to Understand Predictor Effects and How to Modify a Model” on page 9-161

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.step

Purpose Improve linear regression model by adding or removing terms

Syntax

```
mdl1 = step(mdl)
mdl1 = step(mdl,Name,Value)
```

Description `mdl1 = step(mdl)` returns an improved linear model based on `mdl`, with one predictor added or removed.

Note You can use `step` only if `mdl.Robust = []`. This holds when you create `mdl` with `LinearModel.fit` having the `RobustOpts` name-value pair set to the default `'off'`.

`mdl1 = step(mdl,Name,Value)` improves a linear model with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

mdl

Linear model, as constructed by `LinearModel.fit` or `LinearModel.stepwise`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Criterion

Criterion that `step` uses in selecting terms to add or remove:

Criterion	PEnter	PRemove	Compared Against
'SSE'	0.05	< 0.1	p -value for F test
'AIC'	0	< 0.01	Change in AIC
'BIC'	0	< 0.01	Change in BIC
'Rsquared'	0.1	> 0.05	Increase in R-squared
'AdjRsquared'	0	> -0.05	Increase in adjusted R-squared

Default: 'sse'

Lower

Model specification that describes the terms that must exist in the fit.

Default: 'constant'

NSteps

Maximum number of steps to take.

Default: 1

Penter

Improvement measure for adding a term.

- If `Criterion` = 'sse' or 'deviance', `Penter` is the value of p such that, if a term has a p -value less than p , then add the term to the model.
- For other values of `Criterion`, if the improvement in the criterion is more than `Penter`, then add the term to the model.

Default: 0.05 for `Criterion` = 'sse' or 'deviance'; 0 for other values of `Criterion`

LinearModel.step

PRemove

Improvement measure for removing a term.

- If `Criterion = 'sse' or 'deviance'`, `PRemove` is the value of p such that, if a term has a p -value greater than p , then remove the term from the model.
- For other values of `Criterion`, if the improvement in the criterion is less than `Penter`, then remove the term from the model.

Default: 0.1 for `Criterion = 'sse' or 'deviance'`; 0 for other values of `Criterion`

Upper

Model specification describing largest set of terms in the fit.

Default: `'interactions'`

Verbose

Integer from 0 to 2 controlling the display of information.

- 0 suppresses all display.
- 1 displays the action taken at each step.
- 2 also displays the actions evaluated at each step.

Default: 1

Output Arguments

mdl1

Linear model. Typically you set `mdl1` equal to `mdl`.

Examples

Modify a Linear Model

Fit a linear model to car data. Use `step` to see if a quadratic model would help the fit quality.

Load carsmall data, and make a dataset from weight and model year predictors with MPG response.

```
load carsmall
ds = dataset(MPG,Weight);
ds.Year = ordinal(Model_Year);
```

Make a linear model of MPG as a function of Year and Weight.

```
mdl = LinearModel.fit(ds,'MPG ~ Year + Weight')
```

```
mdl =
```

```
Linear regression model:
```

```
MPG ~ 1 + Weight + Year
```

```
Estimated Coefficients:
```

	Estimate	SE	tStat	pValue
(Intercept)	40.11	1.5418	26.016	1.2024e-43
Weight	-0.0066475	0.00042802	-15.531	3.3639e-27
Year_76	1.9291	0.74761	2.5804	0.011488
Year_82	7.9093	0.84975	9.3078	7.8681e-15

```
Number of observations: 94, Error degrees of freedom: 90
```

```
Root Mean Squared Error: 2.92
```

```
R-squared: 0.873, Adjusted R-Squared 0.868
```

```
F-statistic vs. constant model: 206, p-value = 3.83e-40
```

Use step to adjust the model to potentially include full quadratic terms.

```
mdl1 = step(mdl,'upper','quadratic')
```

```
1. Adding Weight^2, FStat = 9.9164, pValue = 0.0022303
```

```
mdl1 =
```

```
Linear regression model:
```

```
MPG ~ 1 + Weight + Year + Weight^2
```

LinearModel.step

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	54.206	4.7117	11.505	2.6648e-19
Weight	-0.016404	0.0031249	-5.2493	1.0283e-06
Year_76	2.0887	0.71491	2.9215	0.0044137
Year_82	8.1864	0.81531	10.041	2.6364e-16
Weight^2	1.5573e-06	4.9454e-07	3.149	0.0022303

Number of observations: 94, Error degrees of freedom: 89

Root Mean Squared Error: 2.78

R-squared: 0.885, Adjusted R-Squared 0.88

F-statistic vs. constant model: 172, p-value = 5.52e-41

Algorithms

Stepwise regression is a systematic method for adding and removing terms from a linear or generalized linear model based on their statistical significance in explaining the response variable. The method begins with an initial model, specified using `modelspec`, and then compares the explanatory power of incrementally larger and smaller models.

MATLAB uses forward and backward stepwise regression to determine a final model. At each step, the method searches for terms to add to or remove from the model based on the value of the 'Criterion' argument. The default value of 'Criterion' is 'sse', and in this case, `LinearModel.stepwise` and `GeneralizedLinearModel.stepwise` use the p -value of an F-statistic to test models with and without a potential term at each step. If a term is not currently in the model, the null hypothesis is that the term would have a zero coefficient if added to the model. If there is sufficient evidence to reject the null hypothesis, the term is added to the model. Conversely, if a term is currently in the model, the null hypothesis is that the term has a zero coefficient. If there is insufficient evidence to reject the null hypothesis, the term is removed from the model.

Here is how stepwise proceeds when 'Criterion' is 'sse':

- 1 Fit the initial model.

- 2** If any terms not in the model have p -values less than an entrance tolerance (that is, if it is unlikely that they would have zero coefficient if added to the model), add the one with the smallest p -value and repeat this step; otherwise, go to step 3.
- 3** If any terms in the model have p -values greater than an exit tolerance (that is, if it is unlikely that the hypothesis of a zero coefficient can be rejected), remove the one with the largest p -value and go to step 2; otherwise, end.

There are several other criteria available, which you can specify using the 'Criterion' argument. You can use the change in the value of the Akaike information criterion, Bayesian information criterion, R-squared, adjusted R-squared, or deviance (only for `GeneralizedLinearModel.stepwise`) as a criterion to add or remove terms.

Depending on the terms included in the initial model and the order in which terms are moved in and out, the method may build different models from the same set of potential terms. The method terminates when no single step improves the model. There is no guarantee, however, that a different initial model or a different sequence of steps will not lead to a better fit. In this sense, stepwise models are locally optimal, but may not be globally optimal.

Alternatives

Use `LinearModel.stepwise` to select a model from a starting model, continuing until no single step is beneficial.

Use `addTerms` or `removeTerms` to add or remove particular terms.

See Also

`addTerms` | `LinearModel` | `removeTerms` | `LinearModel.stepwise`

Tutorials

- “Linear Regression Workflow” on page 9-40
- “Change Models” on page 9-33

How To

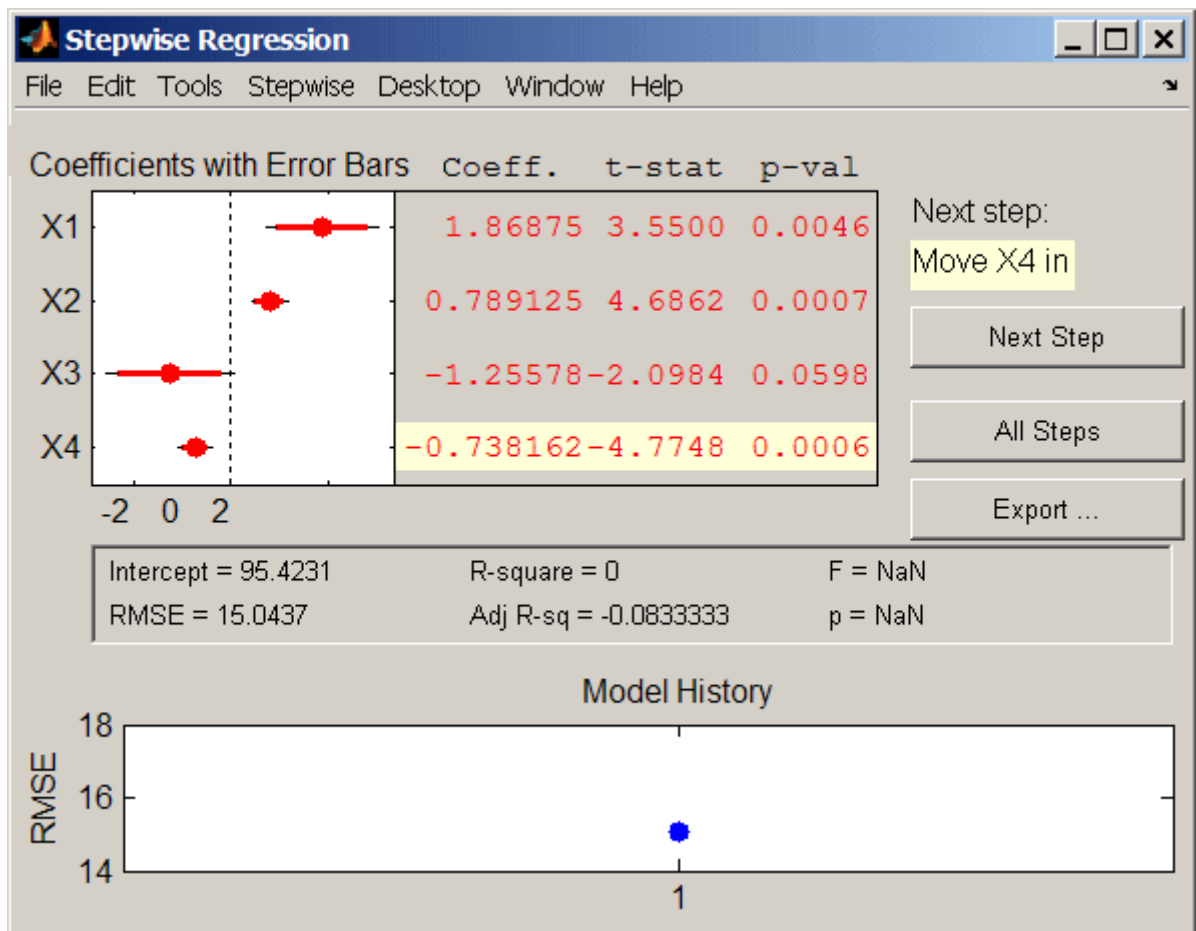
- “Linear Regression” on page 9-7

stepwise

Purpose Interactive stepwise regression

Syntax
`stepwise`
`stepwise(X,y)`
`stepwise(X,y,inmodel,center,remove)`

Description `stepwise` uses the sample data in `hald.mat` to display a graphical user interface for performing stepwise regression of the response values in `heat` on the predictive terms in `ingredients`.



The upper left of the interface displays estimates of the coefficients for all potential terms, with horizontal bars indicating 90% (colored) and 95% (grey) confidence intervals. The red color indicates that, initially, the terms are not in the model. Values displayed in the table are those that would result if the terms were added to the model.

The middle portion of the interface displays summary statistics for the entire model. These statistics are updated with each step.

The lower portion of the interface, **Model History**, displays the RMSE for the model. The plot tracks the RMSE from step to step, so you can compare the optimality of different models. Hover over the blue dots in the history to see which terms were in the model at a particular step. Click on a blue dot in the history to open a copy of the interface initialized with the terms in the model at that step.

Initial models, as well as entrance/exit tolerances for the p -values of F -statistics, are specified using additional input arguments to **stepwise**. Defaults are an initial model with no terms, an entrance tolerance of 0.05, and an exit tolerance of 0.10.

To center and scale the input data (compute z -scores) to improve conditioning of the underlying least-squares problem, select **Scale Inputs** from the **Stepwise** menu.

You proceed through a stepwise regression in one of two ways:

- 1** Click **Next Step** to select the recommended next step. The recommended next step either adds the most significant term or removes the least significant term. When the regression reaches a local minimum of RMSE, the recommended next step is “Move no terms.” You can perform all of the recommended steps at once by clicking **All Steps**.
- 2** Click a line in the plot or in the table to toggle the state of the corresponding term. Clicking a red line, corresponding to a term not currently in the model, adds the term to the model and changes the line to blue. Clicking a blue line, corresponding to a term currently in the model, removes the term from the model and changes the line to red.

To call `addedvarplot` and produce an added variable plot from the **stepwise** interface, select **Added Variable Plot** from the **Stepwise** menu. A list of terms is displayed. Select the term you want to add, and then click **OK**.

Click **Export** to display a dialog box that allows you to select information from the interface to save to the MATLAB workspace.

Check the information you want to export and, optionally, change the names of the workspace variables to be created. Click **OK** to export the information.

`stepwise(X,y)` displays the interface using the p predictive terms in the n -by- p matrix X and the response values in the n -by-1 vector y . Distinct predictive terms should appear in different columns of X .

Note `stepwise` automatically includes a constant term in all models. Do not enter a column of 1s directly into X .

`stepwise` treats NaN values in either X or y as missing values, and ignores them.

`stepwise(X,y,inmodel,penter,premove)` additionally specifies the initial model (`inmodel`) and the entrance (`penter`) and exit (`premove`) tolerances for the p -values of F -statistics. `inmodel` is either a logical vector with length equal to the number of columns of X , or a vector of indices, with values ranging from 1 to the number of columns in X . The value of `penter` must be less than or equal to the value of `premove`.

Algorithms

Stepwise regression is a systematic method for adding and removing terms from a multilinear model based on their statistical significance in a regression. The method begins with an initial model and then compares the explanatory power of incrementally larger and smaller models. At each step, the p value of an F -statistic is computed to test models with and without a potential term. If a term is not currently in the model, the null hypothesis is that the term would have a zero coefficient if added to the model. If there is sufficient evidence to reject the null hypothesis, the term is added to the model. Conversely, if a term is currently in the model, the null hypothesis is that the term has a zero coefficient. If there is insufficient evidence to reject the null hypothesis, the term is removed from the model. The method proceeds as follows:

- 1 Fit the initial model.

stepwise

- 2** If any terms not in the model have p -values less than an entrance tolerance (that is, if it is unlikely that they would have zero coefficient if added to the model), add the one with the smallest p value and repeat this step; otherwise, go to step 3.
- 3** If any terms in the model have p -values greater than an exit tolerance (that is, if it is unlikely that the hypothesis of a zero coefficient can be rejected), remove the one with the largest p value and go to step 2; otherwise, end.

Depending on the terms included in the initial model and the order in which terms are moved in and out, the method may build different models from the same set of potential terms. The method terminates when no single step improves the model. There is no guarantee, however, that a different initial model or a different sequence of steps will not lead to a better fit. In this sense, stepwise models are locally optimal, but may not be globally optimal.

See Also

`addedvarplot` | `regress` | `stepwisefit`

GeneralizedLinearModel.stepwise

Purpose

Create generalized linear regression model by stepwise regression

Syntax

```
mdl = GeneralizedLinearModel.stepwise(ds,modelspec)
mdl = GeneralizedLinearModel.stepwise(X,y,modelspec)
mdl = GeneralizedLinearModel.stepwise(...,modelspec,Name,
    Value)
```

Description

`mdl = GeneralizedLinearModel.stepwise(ds,modelspec)` creates a generalized linear model of a dataset array `ds`, using stepwise regression to add or remove predictors. `modelspec` is the starting model for the stepwise procedure.

`mdl = GeneralizedLinearModel.stepwise(X,y,modelspec)` creates a generalized linear model of the responses `y` to a data matrix `X`, using stepwise regression to add or remove predictors.

`mdl = GeneralizedLinearModel.stepwise(...,modelspec,Name,Value)` creates a generalized linear model with additional options specified by one or more `Name,Value` pair arguments.

Tips

- The generalized linear model `mdl` is a standard linear model unless you specify otherwise with the `Distribution` name-value pair.
- For other methods such as `fit` or `devianceTest`, or properties of the `GeneralizedLinearModel` object, see `GeneralizedLinearModel`.

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors can be numeric, or can be any grouping variable type, such as logical or categorical (see “Grouping Variables” on page 2-72). The response must be numeric or logical.

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

GeneralizedLinearModel.stepwise

x

Matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as X. Each entry in y is the response to the data in the corresponding row of X.

modelspec

Model specification. This is the starting model for the stepwise method. Possibilities:

- String specifying the type of model.

String	Model Type
'constant'	Model contains only a constant (intercept) term.
'linear'	Model contains an intercept and linear terms for each predictor.
'interactions'	Model contains an intercept, linear terms, and all products of pairs of distinct predictors (no squared terms).
'purequadratic'	Model contains an intercept, linear terms, and squared terms.

String	Model Type
'quadratic'	Model contains an intercept, linear terms, interactions, and squared terms.
'polyijk'	Model is a polynomial with all terms up to degree i in the first predictor, degree j in the second predictor, etc. Use numerals 0 through 9. For example, 'poly2111' has a constant plus all linear and product terms, and also contains terms with predictor 1 squared.

- T-by-P+1 matrix, namely “Terms Matrix” on page 20-2358, specifying terms to include in model, where T is the number of terms and P is the number of predictor variables, and plus one is for the response variable.
- String representing a “Formula” on page 20-2362 in the form

`'Y ~ terms'`,

where the terms are in “Wilkinson Notation” on page 20-2363.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

BinomialSize

Vector or name of a variable of the same length as the response, specifying the size of the sample (number of trials) used in fitting the binomial distribution. This is the `n` parameter for the fitted binomial distribution. `BinomialSize` applies only when the `Distribution` parameter is `'binomial'`.

GeneralizedLinearModel.stepwise

`BinomialSize` can be a scalar, meaning all observations have the same number of trials.

As an alternative to `BinomialSize`, you can specify the response as a two-column vector with counts in column 1 and `BinomialSize` in column 2.

Default: 1

CategoricalVars

Identify the categorical variables. Choices:

- Cell array of strings of the variable names in the `ds` dataset array.
- Logical or numerical index vector indicating which data columns are categorical. For example, if predictors 2 and 3 out of 6 are categorical, pass either

`[2,3]`

or

`logical([0 1 1 0 0 0])`

Default: For data matrix `X`, default is `[]` (none). For dataset array `ds`, default is to treat `ds` variables as categorical if they are categorical, logical, character arrays, or cell arrays of strings.

Criterion

Criterion that `stepwise` uses in selecting terms to add or remove:

- `'sse'` — p -value for an F test of the change in sse by adding or removing the term.
- `'deviance'` — p -value for a chi-square test of the change in deviance.
- `'aic'` — Change in the value of AIC.

- 'bic' — Change in the value of BIC.
- 'rsquared' — Change in the value of R^2 .
- 'adjrsquared' — Change in the value of adjusted R^2 .

Default: 'sse'

DispersionFlag

Logical value that applies only to 'binomial' and 'poisson' distributions. `true` causes the fitting function to estimate a dispersion parameter when computing standard errors. `false` causes the fitting function to use the theoretical value. The fitting function always estimates the dispersion for other distributions.

Default: `false` for 'binomial' and 'poisson' distributions

Distribution

Name of the distribution of the response, one of:

'normal'	Normal distribution
'binomial'	Binomial distribution
'poisson'	Poisson distribution
'gamma'	Gamma distribution
'inverse gaussian'	Inverse Gaussian distribution

Default: 'normal'

Exclude

Logical or numerical index vector indicating which observations to exclude from the fit. For example, to exclude observations 2 and 3 out of 6, pass either

GeneralizedLinearModel.stepwise

[2,3]

or

logical([0 1 1 0 0 0])

Default: []

Intercept

Logical value indicating whether to include a constant term (intercept) in the model. Use `Intercept` only when you specify the model by a string, not a formula or matrix.

Default: true

Link

The link function to use in place of the canonical link. The link function defines the relationship $f(\mu) = X*b$ between the mean response μ and the linear combination of predictors $X*b$. Specify the link as follows.

Link Function Name	Link Function	Mean (Inverse) Function
'identity'	$f(\mu) = \mu$	$\mu = Xb$
'log'	$f(\mu) = \log(\mu)$	$\mu = \exp(Xb)$
'logit'	$f(\mu) = \log(\mu/(1-\mu))$	$\mu = \exp(Xb) / (1 + \exp(Xb))$
'probit'	$f(\mu) = \Phi^{-1}(\mu)$	$\mu = \Phi(Xb)$
'comloglog'	$f(\mu) = \log(-\log(1 - \mu))$	$\mu = 1 - \exp(-\exp(Xb))$
'reciprocal'	$f(\mu) = \log(-\log(\mu))$	$\mu = \exp(-\exp(Xb))$

GeneralizedLinearModel.stepwise

Link Function Name	Link Function	Mean (Inverse) Function
p (a number)	$f(\mu) = \mu^p$	$\mu = Xb^{1/p}$
S (a structure) S has three fields, each a function handle that accepts a vector of inputs and returns a vector the same size: <ul style="list-style-type: none">• S.Link — The link function• S.Inverse — The inverse link function• S.Derivative — The derivative of the link function	$f(\mu) = S.Link(\mu)$	$\mu = S.Inverse(Xb)$

Default: The canonical link function (see “Definitions” on page 20-694)

Lower

Model specification that describes the terms that must exist in the fit.

Default: 'constant'

Offset

Vector or name of a variable with the same length as the response. `GeneralizedLinearModel.fit` and `GeneralizedLinearModel.stepwise` use `Offset` as an additional predictor, with a coefficient value fixed at 1.0. In other words, the formula for fitting is

GeneralizedLinearModel.stepwise

$\mu \sim \text{Offset} + (\text{terms involving real predictors})$

with the Offset predictor having coefficient 1.

For example, consider a Poisson regression model. Suppose the number of counts is known for theoretical reasons to be proportional to a predictor A. By using the log link function and by specifying $\log(A)$ as an offset, you can force the model to satisfy this theoretical constraint.

Default: []

Penter

Improvement measure for adding a term.

- If `Criterion = 'sse' or 'deviance'`, Penter is the value of p such that, if a term has a p -value less than p , then add the term to the model.
- For other values of `Criterion`, if the improvement in the criterion is more than Penter, then add the term to the model.

Default: 0.05 for `Criterion = 'sse' or 'deviance'`; 0 for other values of `Criterion`

PredictorVars

Identify the predictors to use for fitting. Choices:

- Cell array of strings of the variable names. The strings should be names in the `ds` dataset array, or the `VarNames` name-value pair.
- Logical or numerical index vector indicating which predictors to use. For example, to use predictors 2 and 3 out of 6, pass either

[2,3]

or

```
logical([0 1 1 0 0 0])
```

Default: All variables in X , or all variables in ds except for `ResponseVar`

PRemove

Improvement measure for removing a term.

- If `Criterion` = 'sse' or 'deviance', `PRemove` is the value of p such that, if a term has a p -value greater than p , then remove the term from the model.
- For other values of `Criterion`, if the improvement in the criterion is less than `Penter`, then remove the term from the model.

Default: 0.1 for `Criterion` = 'sse' or 'deviance'; 0 for other values of `Criterion`

ResponseVar

Variable that the fitting function uses for response data. Give either the variable name or its column number. Typically, you use `ResponseVar` when fitting a dataset array ds . Choices are:

- String of the variable name.
- Logical or numerical index vector indicating which predictors to use. For example, to use the fourth variable as the response out of six variables, pass either

```
'ResponseVar', [4]
```

or

```
'ResponseVar', logical([0 0 0 1 0 0])
```

Default: Last column of ds

GeneralizedLinearModel.stepwise

Upper

Model specification describing largest set of terms in the fit.

Default: 'interactions'

VarNames

Cell array of strings, first naming the columns of X, and with the response variable y last. Not applicable to variables in a dataset array, because those variables already have names.

Default: {'x1', 'x2', ..., 'xn', 'y'}, where n is the number of columns of X

Weights

Vector of nonnegative observation weights.

Default: ones(size(y))

Output Arguments

mdl

Generalized linear model representing a least-squares fit of the link of the response to the data.

Definitions

Terms Matrix

A terms matrix is a T-by-P+1 matrix specifying terms in a model, where T is the number of terms, P is the number of predictor variables, and plus one is for the response variable. The value of $T(i, j)$ is the exponent of variable j in term i. For example, if there are three predictor variables A, B, and C:

```
[0 0 0 0] % constant term or intercept
[0 1 0 0] % B; equivalently, A^0 * B^1 * C^0
[1 0 1 0] % A*C
[2 0 0 0] % A^2
[0 1 2 0] % B*(C^2)
```


GeneralizedLinearModel.stepwise

The 0 at the end of each term represents the response variable. In general,

- If you have the variables in a dataset array, then a 0 must represent the response variable depending on the position of the response variable in the dataset array. For example:

Load sample data and define the dataset array.

```
load hospital
ds = dataset(hospital.Sex,hospital.BloodPressure(:,1),hospital.Age,
hospital.Smoker,'VarNames',{'Sex','BloodPressure','Age','Smoker'});
```

Represent the linear model 'BloodPressure ~ 1 + Sex + Age + Smoker' in a terms matrix. The response variable is in the second column of the data set array, so there must be a column of zeros for the response variable in the second column of the term matrix.

```
T = [0 0 0 0;1 0 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```
    0    0    0    0
    1    0    0    0
    0    0    1    0
    0    0    0    1
```

Redefine the dataset array.

```
ds = dataset(hospital.BloodPressure(:,1),hospital.Sex,hospital.Age,
hospital.Smoker,'VarNames',{'BloodPressure','Sex','Age','Smoker'});
```

Now, the response variable is the first term in the data set array. Specify the same linear model, 'BloodPressure ~ 1 + Sex + Age + Smoker', using a term matrix.

```
T = [0 0 0 0;0 1 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

GeneralizedLinearModel.stepwise

```
0 0 0 0
0 1 0 0
0 0 1 0
0 0 0 1
```

- If you have the predictor and response variables in a matrix and column vector, then you must include a 0 for the response variable at the end of each term. For example:

Load sample data and define the matrix of predictors.

```
load carsmall
X = [Acceleration,Weight];
```

Specify the model 'MPG ~ Acceleration + Weight + Acceleration:Weight + Weight^2' using a term matrix and fit the model to data. This model includes the main effect and two way interaction terms for the variables, Acceleration and Weight, and a second order term for the variable, Weight.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0;0 2 0]
```

```
T =
```

```
0 0 0
1 0 0
0 1 0
1 1 0
0 2 0
```

Fit a linear model.

```
mdl = LinearModel.fit(X,MPG,T)
```

```
mdl =
```

```
Linear regression model:
```

GeneralizedLinearModel.stepwise

$$y \sim 1 + x1*x2 + x2^2$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	48.906	12.589	3.8847	0.000196
x1	0.54418	0.57125	0.95261	0.343
x2	-0.012781	0.0060312	-2.1192	0.0368
x1:x2	-0.00010892	0.00017925	-0.6076	0.5
x2^2	9.7518e-07	7.5389e-07	1.2935	0.199

Number of observations: 94, Error degrees of freedom: 89

Root Mean Squared Error: 4.1

R-squared: 0.751, Adjusted R-Squared 0.739

F-statistic vs. constant model: 67, p-value = 4.99e-26

Only the intercept and x2 term, which corresponds to the Weight variable, are significant at the 5% significance level.

Now, perform a stepwise regression with a constant model as the starting model and a linear model with interactions as the upper model.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0];
```

```
mdl = LinearModel.stepwise(X,MPG,[0 0 0],'upper',T)
```

1. Adding x2, FStat = 259.3087, pValue = 1.643351e-28

```
mdl =
```

Linear regression model:

$$y \sim 1 + x2$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	49.238	1.6411	30.002	2.7015e-49
x2	-0.0086119	0.0005348	-16.103	1.6434e-28

Number of observations: 94, Error degrees of freedom: 92

GeneralizedLinearModel.stepwise

```
Root Mean Squared Error: 4.13
R-squared: 0.738, Adjusted R-Squared 0.735
F-statistic vs. constant model: 259, p-value = 1.64e-28
```

The results of the stepwise regression are consistent with the results of `LinearModel.fit` in the previous step.

Formula

A formula for model specification is a string of the form

```
'Y ~ terms',
```

where

- Y is the response name.
- $terms$ contains
 - Variable names
 - $+$ means include the next variable
 - $-$ means do not include the next variable
 - $:$ defines an interaction, a product of terms
 - $*$ defines an interaction **and all lower-order terms**
 - $^$ raises the predictor to a power, exactly as in $*$ repeated, so $^$ includes lower order terms as well
 - $()$ groups terms

Note Formulas include a constant (intercept) term by default. To exclude a constant term from the model, include -1 in the formula.

For example,

'Y ~ A + B + C' means a three-variable linear model with intercept.

'Y ~ A + B + C - 1' is a three-variable linear model without intercept.

'Y ~ A + B + C + B^2' is a three-variable model with intercept and a B^2 term.

'Y ~ A + B^2 + C' is the same as the previous example because B^2 includes a B term.

'Y ~ A + B + C + A:B' includes an A*B term.

'Y ~ A*B + C' is the same as the previous example because $A*B = A + B + A:B$.

'Y ~ A*B*C - A:B:C' has all interactions among A, B, and C, except the three-way interaction.

'Y ~ A*(B + C + D)' has all linear terms, plus products of A with each of the other variables.

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k, where k is a positive integer	A, A ² , ..., A ^k
A+B	A, B
A*B	A, B, A*B
A:B	A*B only
-B	Do not include B
A*B+C	A, B, C, A*B
A+B+C+A:B	A, B, C, A*B
A*B*C - A:B:C	A, B, C, A*B, A*C, B*C
A*(B + C)	A, B, C, A*B, A*C

GeneralizedLinearModel.stepwise

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using -1.

Canonical Link Function

The default link function for a generalized linear model is the *canonical link function*.

Canonical Link Functions for Generalized Linear Models

Distribution	Link Function Name	Link Function	Mean (Inverse) Function
'normal'	'identity'	$f(\mu) = \mu$	$\mu = Xb$
'binomial'	'logit'	$f(\mu) = \log(\mu/(1-\mu))$	$\mu = \exp(Xb) / (1 + \exp(Xb))$
'poisson'	'log'	$f(\mu) = \log(\mu)$	$\mu = \exp(Xb)$
'gamma'	-1	$f(\mu) = 1/\mu$	$\mu = 1/(Xb)$
'inverse gaussian'	-2	$f(\mu) = 1/\mu^2$	$\mu = (Xb)^{-1/2}$

Examples

Create a Generalized Linear Model Stepwise

Create response data using just three of 20 predictors, and create a generalized linear model stepwise to see if it uses just the correct predictors.

Create data with 20 predictors, and Poisson response using just three of the predictors, plus a constant.

```
rng('default') % for reproducibility
X = randn(100,20);
mu = exp(X(:, [5 10 15]) * [.4;.2;.3] + 1);
y = poissrnd(mu);
```

Fit a generalized linear model using the Poisson distribution.

```
mdl = GeneralizedLinearModel.stepwise(X,y,...
```

```
'constant','upper','linear','Distribution','poisson')

1. Adding x5, Deviance = 134.439, Chi2Stat = 52.24814, PValue = 4.891229e-13
2. Adding x15, Deviance = 106.285, Chi2Stat = 28.15393, PValue = 1.1204e-07
3. Adding x10, Deviance = 95.0207, Chi2Stat = 11.2644, PValue = 0.000790094

mdl =

Generalized Linear regression model:
log(y) ~ 1 + x5 + x10 + x15
Distribution = Poisson

Estimated Coefficients:
              Estimate    SE      tStat    pValue
(Intercept)    1.0115    0.064275    15.737    8.4217e-56
x5              0.39508    0.066665     5.9263    3.0977e-09
x10             0.18863     0.05534     3.4085    0.0006532
x15             0.29295     0.053269     5.4995    3.8089e-08

100 observations, 96 error degrees of freedom
Dispersion: 1
Chi^2-statistic vs. constant model: 91.7, p-value = 9.61e-20
```

Algorithms

Stepwise regression is a systematic method for adding and removing terms from a linear or generalized linear model based on their statistical significance in explaining the response variable. The method begins with an initial model, specified using `modelspec`, and then compares the explanatory power of incrementally larger and smaller models.

MATLAB uses forward and backward stepwise regression to determine a final model. At each step, the method searches for terms to add to or remove from the model based on the value of the 'Criterion' argument. The default value of 'Criterion' is 'sse', and in this case, `LinearModel.stepwise` and `GeneralizedLinearModel.stepwise` use the p -value of an F-statistic to test models with and without a potential term at each step. If a term is not currently in the model, the null

GeneralizedLinearModel.stepwise

hypothesis is that the term would have a zero coefficient if added to the model. If there is sufficient evidence to reject the null hypothesis, the term is added to the model. Conversely, if a term is currently in the model, the null hypothesis is that the term has a zero coefficient. If there is insufficient evidence to reject the null hypothesis, the term is removed from the model.

Here is how stepwise proceeds when 'Criterion' is 'sse':

- 1** Fit the initial model.
- 2** If any terms not in the model have p -values less than an entrance tolerance (that is, if it is unlikely that they would have zero coefficient if added to the model), add the one with the smallest p -value and repeat this step; otherwise, go to step 3.
- 3** If any terms in the model have p -values greater than an exit tolerance (that is, if it is unlikely that the hypothesis of a zero coefficient can be rejected), remove the one with the largest p -value and go to step 2; otherwise, end.

There are several other criteria available, which you can specify using the 'Criterion' argument. You can use the change in the value of the Akaike information criterion, Bayesian information criterion, R-squared, adjusted R-squared, or deviance (only for `GeneralizedLinearModel.stepwise`) as a criterion to add or remove terms.

Depending on the terms included in the initial model and the order in which terms are moved in and out, the method may build different models from the same set of potential terms. The method terminates when no single step improves the model. There is no guarantee, however, that a different initial model or a different sequence of steps will not lead to a better fit. In this sense, stepwise models are locally optimal, but may not be globally optimal.

Alternatives

Use `GeneralizedLinearModel.fit` to create a model with a fixed specification. Use `step`, `addTerms`, or `removeTerms` to adjust a fitted model.

References

[1] Collett, D. *Modeling Binary Data*. New York: Chapman & Hall, 2002.

[2] Dobson, A. J. *An Introduction to Generalized Linear Models*. New York: Chapman & Hall, 1990.

[3] McCullagh, P., and J. A. Nelder. *Generalized Linear Models*. New York: Chapman & Hall, 1990.

See Also

`GeneralizedLinearModel` | `GeneralizedLinearModel.fit` |

Related Examples

- “Compare large and small stepwise models” on page 9-108

Concepts

- “Generalized Linear Models” on page 9-141

LinearModel.stepwise

Purpose Create linear regression model by stepwise regression

Syntax

```
mdl = LinearModel.stepwise(ds,modelspec)
mdl = LinearModel.stepwise(X,y,modelspec)
mdl = LinearModel.stepwise( __ ,modelspec,Name,Value)
```

Description

`mdl = LinearModel.stepwise(ds,modelspec)` returns a linear model of a dataset array `ds`, using stepwise regression to add or remove predictors. `modelspec` is the starting model for the stepwise procedure.

`mdl = LinearModel.stepwise(X,y,modelspec)` creates a linear model of the responses `y` to a data matrix `X`, using stepwise regression to add or remove predictors. `modelspec` is the starting model for the stepwise procedure.

`mdl = LinearModel.stepwise(__ ,modelspec,Name,Value)` creates a linear model for any of the inputs in the previous syntaxes, with additional options specified by one or more `NAME,Value` pair arguments. `modelspec` is the starting model for the stepwise procedure.

- Tips**
- You cannot use robust regression with stepwise regression. Check your data for outliers before using `LinearModel.stepwise`.
 - For other methods such as `fit` or `anova`, or properties of the `LinearModel` object, see `LinearModel`.

Input Arguments

ds

Dataset array, where by default the last column is the response variable, and all other columns are the predictors. Predictors can be numeric, or can be any grouping variable type, such as logical or categorical (see “Grouping Variables” on page 2-72). The response must be numeric or logical.

To set a different column as the response variable, use the `ResponseVar` name-value pair. To use a subset of the columns as predictors, use the `PredictorVars` name-value pair.

X

Matrix of predictor values. Each column of X represents one variable, and each row represents one observation.

y

Vector of response values with the same number of rows as X . Each entry in y is the response to the data in the corresponding row of X .

modelspec

Model specification. This is the starting model for the stepwise method. Possibilities:

- String specifying the type of model.

String	Model Type
'constant'	Model contains only a constant (intercept) term.
'linear'	Model contains an intercept and linear terms for each predictor.
'interactions'	Model contains an intercept, linear terms, and all products of pairs of distinct predictors (no squared terms).
'purequadratic'	Model contains an intercept, linear terms, and squared terms.
'quadratic'	Model contains an intercept, linear terms, interactions, and squared terms.
'polyijk'	Model is a polynomial with all terms up to degree i in the first predictor, degree j in the second predictor, etc. Use numerals 0 through 9. For example, 'poly2111' has a constant plus all linear and product terms, and also contains terms with predictor 1 squared.

- T-by-P+1 matrix, namely “Terms Matrix” on page 20-2374 , specifying terms to include in model, where T is the number of terms and P is the number of predictor variables, and plus one is for the response variable.
- String representing a “Formula” on page 20-2378 in the form

`'Y ~ terms'`,

where the terms are in “Wilkinson Notation” on page 20-2379.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name`, `Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

CategoricalVars

Identify the categorical variables. Choices:

- Cell array of strings of the variable names in the `ds` dataset array.
- Logical or numerical index vector indicating which data columns are categorical. For example, if predictors 2 and 3 out of 6 are categorical, pass either

`[2,3]`

or

`logical([0 1 1 0 0 0])`

Default: For data matrix `X`, default is `[]` (none). For dataset array `ds`, default is to treat `ds` variables as categorical if they are categorical, logical, character arrays, or cell arrays of strings.

Criterion

Criterion that `stepwise` uses in selecting terms to add or remove:

- 'sse' — p -value for an F test of the change in sse by adding or removing the term.
- 'aic' — Change in the value of AIC.
- 'bic' — Change in the value of BIC.
- 'rsquared' — Change in the value of R^2 .
- 'adjrsquared' — Change in the value of adjusted R^2 .

Default: 'sse'

Exclude

Logical or numerical index vector indicating which observations to exclude from the fit. For example, to exclude observations 2 and 3 out of 6, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: []

Intercept

Logical value indicating whether to include a constant term (intercept) in the model. Use `Intercept` only when you specify the model by a string, not a formula or matrix.

Default: true

Lower

LinearModel.stepwise

Model specification that describes the terms that must exist in the fit.

Default: 'constant'

NSteps

Maximum number of steps to take.

Default: 1

Penter

Improvement measure for adding a term.

- If `Criterion = 'sse'`, `Penter` is the value of p such that, if a term has a p -value less than p , then add the term to the model.
- For other values of `Criterion`, if the improvement in the criterion is more than `Penter`, then add the term to the model.

Default: 0.05 for `Criterion = 'sse'`; 0 for other values of `Criterion`

PredictorVars

Identify the predictors to use for fitting. Choices:

- Cell array of strings of the variable names. The strings should be names in the `ds` dataset array, or the `VarNames` name-value pair.
- Logical or numerical index vector indicating which predictors to use. For example, to use predictors 2 and 3 out of 6, pass either

```
[2,3]
```

or

```
logical([0 1 1 0 0 0])
```

Default: All variables in X , or all variables in ds except for `ResponseVar`

PRemove

Improvement measure for removing a term.

- If `Criterion = 'sse'`, `PRemove` is the value of p such that, if a term has a p -value greater than p , then remove the term from the model.
- For other values of `Criterion`, if the improvement in the criterion is less than `Penter`, then remove the term from the model.

Default: 0.1 for `Criterion = 'sse'`; 0 for other values of `Criterion`

ResponseVar

Variable that the fitting function uses for response data. Give either the variable name or its column number. Typically, you use `ResponseVar` when fitting a dataset array ds . Choices are:

- String of the variable name.
- Logical or numerical index vector indicating which predictors to use. For example, to use the fourth variable as the response out of six variables, pass either

```
'ResponseVar', [4]
```

or

```
'ResponseVar', logical([0 0 0 1 0 0])
```

Default: Last column of ds

Upper

LinearModel.stepwise

Model specification describing largest set of terms in the fit.

Default: 'interactions'

VarNames

Cell array of strings, first naming the columns of X, and with the response variable y last. Not applicable to variables in a dataset array, because those variables already have names.

Default: { 'x1', 'x2', ..., 'xn', 'y' }, where n is the number of columns of X

Verbose

Integer from 0 to 2 controlling the display of information.

- 0 suppresses all display.
- 1 displays the action taken at each step.
- 2 also displays the actions evaluated at each step.

Default: 1

Weights

Vector of nonnegative observation weights.

Default: ones(size(y))

Output Arguments

mdl

Linear model representing a least-squares fit of the response to the data.

Definitions

Terms Matrix

A terms matrix is a T-by-P+1 matrix specifying terms in a model, where T is the number of terms, P is the number of predictor variables,

and plus one is for the response variable. The value of $T(i, j)$ is the exponent of variable j in term i . For example, if there are three predictor variables A, B, and C:

```
[0 0 0 0] % constant term or intercept
[0 1 0 0] % B; equivalently, A^0 * B^1 * C^0
[1 0 1 0] % A*C
[2 0 0 0] % A^2
[0 1 2 0] % B*(C^2)
```

The 0 at the end of each term represents the response variable. In general,

- If you have the variables in a dataset array, then a 0 must represent the response variable depending on the position of the response variable in the dataset array. For example:

Load sample data and define the dataset array.

```
load hospital
ds = dataset(hospital.Sex,hospital.BloodPressure(:,1),hospital.Age,
hospital.Smoker,'VarNames',{'Sex','BloodPressure','Age','Smoker'});
```

Represent the linear model 'BloodPressure ~ 1 + Sex + Age + Smoker' in a terms matrix. The response variable is in the second column of the data set array, so there must be a column of zeros for the response variable in the second column of the term matrix.

```
T = [0 0 0 0;1 0 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```
    0    0    0    0
    1    0    0    0
    0    0    1    0
    0    0    0    1
```

Redefine the dataset array.

LinearModel.stepwise

```
ds = dataset(hospital.BloodPressure(:,1),hospital.Sex,hospital.Age,...
hospital.Smoker,'VarNames',{'BloodPressure','Sex','Age','Smoker'});
```

Now, the response variable is the first term in the data set array. Specify the same linear model, 'BloodPressure ~ 1 + Sex + Age + Smoker', using a term matrix.

```
T = [0 0 0 0;0 1 0 0;0 0 1 0;0 0 0 1]
```

```
T =
```

```
    0    0    0    0
    0    1    0    0
    0    0    1    0
    0    0    0    1
```

- If you have the predictor and response variables in a matrix and column vector, then you must include a 0 for the response variable at the end of each term. For example:

Load sample data and define the matrix of predictors.

```
load carsmall
X = [Acceleration,Weight];
```

Specify the model 'MPG ~ Acceleration + Weight + Acceleration:Weight + Weight^2' using a term matrix and fit the model to data. This model includes the main effect and two way interaction terms for the variables, Acceleration and Weight, and a second order term for the variable, Weight.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0;0 2 0]
```

```
T =
```

```
    0    0    0
    1    0    0
    0    1    0
```

```
      1      1      0
      0      2      0
```

Fit a linear model.

```
mdl = LinearModel.fit(X,MPG,T)
```

```
mdl =
```

Linear regression model:

```
y ~ 1 + x1*x2 + x2^2
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	48.906	12.589	3.8847	0.000196
x1	0.54418	0.57125	0.95261	0.343
x2	-0.012781	0.0060312	-2.1192	0.0368
x1:x2	-0.00010892	0.00017925	-0.6076	0.5
x2^2	9.7518e-07	7.5389e-07	1.2935	0.199

Number of observations: 94, Error degrees of freedom: 89

Root Mean Squared Error: 4.1

R-squared: 0.751, Adjusted R-Squared 0.739

F-statistic vs. constant model: 67, p-value = 4.99e-26

Only the intercept and x2 term, which corresponds to the Weight variable, are significant at the 5% significance level.

Now, perform a stepwise regression with a constant model as the starting model and a linear model with interactions as the upper model.

```
T = [0 0 0;1 0 0;0 1 0;1 1 0];
```

```
mdl = LinearModel.stepwise(X,MPG,[0 0 0],'upper',T)
```

1. Adding x2, FStat = 259.3087, pValue = 1.643351e-28

```
mdl =
```

LinearModel.stepwise

Linear regression model:

$$y \sim 1 + x2$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	49.238	1.6411	30.002	2.7015e-49
x2	-0.0086119	0.0005348	-16.103	1.6434e-28

Number of observations: 94, Error degrees of freedom: 92

Root Mean Squared Error: 4.13

R-squared: 0.738, Adjusted R-Squared 0.735

F-statistic vs. constant model: 259, p-value = 1.64e-28

The results of the stepwise regression are consistent with the results of `LinearModel.fit` in the previous step.

Formula

A formula for model specification is a string of the form

```
'Y ~ terms',
```

where

- *Y* is the response name.
- *terms* contains
 - Variable names
 - + means include the next variable
 - - means do not include the next variable
 - : defines an interaction, a product of terms
 - * defines an interaction **and all lower-order terms**
 - ^ raises the predictor to a power, exactly as in * repeated, so ^ includes lower order terms as well

- () groups terms

Note Formulas include a constant (intercept) term by default. To exclude a constant term from the model, include - 1 in the formula.

For example,

'Y ~ A + B + C' means a three-variable linear model with intercept.

'Y ~ A + B + C - 1' is a three-variable linear model without intercept.

'Y ~ A + B + C + B^2' is a three-variable model with intercept and a B^2 term.

'Y ~ A + B^2 + C' is the same as the previous example because B^2 includes a B term.

'Y ~ A + B + C + A:B' includes an A*B term.

'Y ~ A*B + C' is the same as the previous example because $A*B = A + B + A:B$.

'Y ~ A*B*C - A:B:C' has all interactions among A, B, and C, except the three-way interaction.

'Y ~ A*(B + C + D)' has all linear terms, plus products of A with each of the other variables.

Wilkinson Notation

Wilkinson notation describes the factors present in models. The notation relates to factors present in models, not to the multipliers (coefficients) of those factors.

Wilkinson Notation	Factors in Standard Notation
1	Constant (intercept) term
A^k, where k is a positive integer	A, A ² , ..., A ^k
A+B	A, B
A*B	A, B, A*B

LinearModel.stepwise

Wilkinson Notation	Factors in Standard Notation
A:B	A*B only
-B	Do not include B
A*B+C	A, B, C, A*B
A+B+C+A:B	A, B, C, A*B
A*B*C - A:B:C	A, B, C, A*B, A*C, B*C
A*(B + C)	A, B, C, A*B, A*C

Statistics Toolbox notation always includes a constant term unless you explicitly remove the term using -1.

Examples

Linear Model from Stepwise Regression

Fit a linear model of the Hald data using stepwise regression.

Load the data.

```
load hald
```

Fit a linear model to the data.

```
mdl = LinearModel.stepwise(ingredients,heat,'PEnter',0.06)
```

1. Adding x4, FStat = 22.7985, pValue = 0.000576232
2. Adding x1, FStat = 108.2239, pValue = 1.105281e-06
3. Adding x2, FStat = 5.0259, pValue = 0.051687
4. Removing x4, FStat = 1.8633, pValue = 0.2054

```
mdl =
```

Linear regression model:

$$y \sim 1 + x1 + x2$$

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	52.577	2.2862	22.998	5.4566e-10
x1	1.4683	0.1213	12.105	2.6922e-07
x2	0.66225	0.045855	14.442	5.029e-08

Number of observations: 13, Error degrees of freedom: 10
Root Mean Squared Error: 2.41
R-squared: 0.979, Adjusted R-Squared 0.974
F-statistic vs. constant model: 230, p-value = 4.41e-09

Simultaneously Specify the Variables and Use Formula

Simultaneously identify response and predictor variables and specify the initial model using formula in stepwise regression.

Load sample data.

```
load hospital
```

Fit a linear model to the data.

```
mdl = LinearModel.stepwise(hospital, 'Weight~1+Smoker', ...  
    'ResponseVar', 'Weight', 'PredictorVars', {'Sex', 'Age', 'Smoker'}, ...  
    'CategoricalVar', {'Sex', 'Smoker'})
```

1. Adding Sex, FStat = 770.0158, pValue = 6.262758e-48
2. Removing Smoker, FStat = 0.21224, pValue = 0.64605

```
mdl =
```

```
Linear regression model:  
Weight ~ 1 + Sex
```

Estimated Coefficients:

	Estimate	SE	tStat	pValue
(Intercept)	130.47	1.1995	108.77	5.2762e-104
Sex_Male	50.06	1.7496	28.612	2.2464e-49

LinearModel.stepwise

Number of observations: 100, Error degrees of freedom: 98
Root Mean Squared Error: 8.73
R-squared: 0.893, Adjusted R-Squared 0.892
F-statistic vs. constant model: 819, p-value = 2.25e-49

The weight of the patients do not seem to differ significantly according to age or the status of smoking, or interaction of these factors with gender. `LinearModel.stepwise` only includes Sex in the final linear model.

Algorithms

Stepwise regression is a systematic method for adding and removing terms from a linear or generalized linear model based on their statistical significance in explaining the response variable. The method begins with an initial model, specified using `modelspec`, and then compares the explanatory power of incrementally larger and smaller models.

MATLAB uses forward and backward stepwise regression to determine a final model. At each step, the method searches for terms to add to or remove from the model based on the value of the 'Criterion' argument. The default value of 'Criterion' is 'sse', and in this case, `LinearModel.stepwise` and `GeneralizedLinearModel.stepwise` use the p -value of an F-statistic to test models with and without a potential term at each step. If a term is not currently in the model, the null hypothesis is that the term would have a zero coefficient if added to the model. If there is sufficient evidence to reject the null hypothesis, the term is added to the model. Conversely, if a term is currently in the model, the null hypothesis is that the term has a zero coefficient. If there is insufficient evidence to reject the null hypothesis, the term is removed from the model.

Here is how stepwise proceeds when 'Criterion' is 'sse':

- 1 Fit the initial model.
- 2 If any terms not in the model have p -values less than an entrance tolerance (that is, if it is unlikely that they would have zero coefficient if added to the model), add the one with the smallest p -value and repeat this step; otherwise, go to step 3.

- 3 If any terms in the model have p -values greater than an exit tolerance (that is, if it is unlikely that the hypothesis of a zero coefficient can be rejected), remove the one with the largest p -value and go to step 2; otherwise, end.

There are several other criteria available, which you can specify using the 'Criterion' argument. You can use the change in the value of the Akaike information criterion, Bayesian information criterion, R-squared, adjusted R-squared, or deviance (only for `GeneralizedLinearModel.stepwise`) as a criterion to add or remove terms.

Depending on the terms included in the initial model and the order in which terms are moved in and out, the method may build different models from the same set of potential terms. The method terminates when no single step improves the model. There is no guarantee, however, that a different initial model or a different sequence of steps will not lead to a better fit. In this sense, stepwise models are locally optimal, but may not be globally optimal.

References

[1] Draper, N. R., and H. Smith. *Applied Regression Analysis*. Hoboken, NJ: Wiley-Interscience, pp. 307–312, 1998.

Alternatives

You can construct a model using `LinearModel.fit`, then manually adjust the model using `step`, `addTerms`, or `removeTerms`. Use `LinearModel.fit` for robust regression. You cannot use robust regression and stepwise regression together.

See Also

`LinearModel` | `LinearModel.fit` | `step`

Tutorials

- “Compare large and small stepwise models” on page 9-108

How To

- “Linear Regression” on page 9-7
- “Stepwise Regression” on page 9-108

stepwisefit

Purpose

Stepwise regression

Syntax

```
b = stepwisefit(X,y)
[b,se,pval,inmodel,stats,nextstep,history] = stepwisefit(...)
[...] = stepwisefit(X,y,param1,va11,param2,va12,...)
```

Description

`b = stepwisefit(X,y)` uses a stepwise method to perform a multilinear regression of the response values in the n -by-1 vector y on the p predictive terms in the n -by- p matrix X . Distinct predictive terms should appear in different columns of X .

b is a p -by-1 vector of estimated coefficients for all of the terms in X . The `stepwisefit` function calculates the coefficient estimate values in b as follows:

- If a term is not in the final model, then the corresponding coefficient estimate in b results from adding only that term to the predictors in the final model.
- If a term is in the final model, then the coefficient estimate in b for that term is a result of the final model, that is `stepwise` does not consider the terms it excluded from the model while computing these values.

Note `stepwisefit` automatically includes a constant term in all models. Do not enter a column of 1s directly into X .

`stepwisefit` treats NaN values in either X or y as missing values, and ignores them.

`[b,se,pval,inmodel,stats,nextstep,history] = stepwisefit(...)` returns the following additional information:

- `se` — A vector of standard errors for b
- `pval` — A vector of p -values for testing whether elements of b are 0

- `inmodel` — A logical vector, with length equal to the number of columns in `X`, specifying which terms are in the final model
- `stats` — A structure of additional statistics with the following fields. All statistics pertain to the final model except where noted.
 - `source` — The string `'stepwisefit'`
 - `dfe` — Degrees of freedom for error
 - `df0` — Degrees of freedom for the regression
 - `SStotal` — Total sum of squares of the response
 - `SSresid` — Sum of squares of the residuals
 - `fstat` — F -statistic for testing the final model vs. no model (mean only)
 - `pval` — p value of the F -statistic
 - `rmse` — Root mean square error
 - `xr` — Residuals for predictors not in the final model, after removing the part of them explained by predictors in the model
 - `yr` — Residuals for the response using predictors in the final model
 - `B` — Coefficients for terms in final model, with values for a term not in the model set to the value that would be obtained by adding that term to the model
 - `SE` — Standard errors for coefficient estimates
 - `TSTAT` — t statistics for coefficient estimates
 - `PVAL` — p -values for coefficient estimates
 - `intercept` — Estimated intercept
 - `wasnan` — Indicates which rows in the data contained NaN values
- `nextstep` — The recommended next step—either the index of the next term to move in or out of the model, or 0 if no further steps are recommended

stepwisefit

- **history** — Structure containing information on steps taken, with the following fields:
 - **B** — Matrix of regression coefficients, where each column is one step, and each row is one coefficient.
 - **rmse** — Root mean square errors for the model at each step.
 - **df0** — Degrees of freedom for the regression at each step.
 - **in** — Logical array indicating which predictors are in the model at each step, where each row is one step, and each column is one predictor.

`[...] = stepwisefit(X,y,param1,val1,param2,val2,...)`
specifies one or more of the name/value pairs described in the following table.

Parameter	Value
'inmodel'	A logical vector specifying terms to include in the initial fit. The default is to specify no terms.
'penter'	The maximum p value for a term to be added. The default is 0.05.
'premove'	The minimum p value for a term to be removed. The default is the maximum of the value of 'penter' and 0.10.
'display'	'on' displays information about each step in the command window. This is the default. 'off' omits the display.
'maxiter'	The maximum number of steps in the regression. The default is Inf.

Parameter	Value
'keep'	A logical vector specifying terms to keep in their initial state. The default is to specify no terms.
'scale'	'on' centers and scales each column of X (computes z-scores) before fitting. 'off' does not scale the terms. This is the default.

Algorithms

Stepwise regression is a systematic method for adding and removing terms from a multilinear model based on their statistical significance in a regression. The method begins with an initial model and then compares the explanatory power of incrementally larger and smaller models. At each step, the p value of an F -statistic is computed to test models with and without a potential term. If a term is not currently in the model, the null hypothesis is that the term would have a zero coefficient if added to the model. If there is sufficient evidence to reject the null hypothesis, the term is added to the model. Conversely, if a term is currently in the model, the null hypothesis is that the term has a zero coefficient. If there is insufficient evidence to reject the null hypothesis, the term is removed from the model. The method proceeds as follows:

- 1** Fit the initial model.
- 2** If any terms not in the model have p -values less than an entrance tolerance (that is, if it is unlikely that they would have zero coefficient if added to the model), add the one with the smallest p value and repeat this step; otherwise, go to step 3.
- 3** If any terms in the model have p -values greater than an exit tolerance (that is, if it is unlikely that the hypothesis of a zero coefficient can be rejected), remove the one with the largest p value and go to step 2; otherwise, end.

Depending on the terms included in the initial model and the order in which terms are moved in and out, the method may build different

stepwisefit

models from the same set of potential terms. The method terminates when no single step improves the model. There is no guarantee, however, that a different initial model or a different sequence of steps will not lead to a better fit. In this sense, stepwise models are locally optimal, but may not be globally optimal.

Examples

Load the data in `hald.mat`, which contains observations of the heat of reaction of various cement mixtures:

```
load hald
whos
```

Name	Size	Bytes	Class	Attributes
Description	22x58	2552	char	
hald	13x5	520	double	
heat	13x1	104	double	
ingredients	13x4	416	double	

The response (heat) depends on the quantities of the four predictors (the columns of `ingredients`).

Use `stepwisefit` to carry out the stepwise regression algorithm, beginning with no terms in the model and using entrance/exit tolerances of 0.05/0.10 on the p -values:

```
stepwisefit(ingredients,heat,...
            'penter',0.05,'premove',0.10);
Initial columns included: none
Step 1, added column 4, p=0.000576232
Step 2, added column 1, p=1.10528e-006
Final columns included: 1 4
```

'Coeff'	'Std.Err.'	'Status'	'P'
[1.4400]	[0.1384]	'In'	[1.1053e-006]
[0.4161]	[0.1856]	'Out'	[0.0517]
[-0.4100]	[0.1992]	'Out'	[0.0697]
[-0.6140]	[0.0486]	'In'	[1.8149e-007]

stepwisefit automatically includes an intercept term in the model, so you do not add it explicitly to ingredients as you would for regress. For terms not in the model, coefficient estimates and their standard errors are those that result by adding the corresponding term to the final model.

The inmodel parameter is used to specify terms in an initial model:

```
initialModel = ...
    [false true false false]; % Force in 2nd term
stepwisefit(ingredients,heat,...
    'inmodel',initialModel,...
    'penter',.05,'premove',0.10);
```

Initial columns included: 2

Step 1, added column 1, p=2.69221e-007

Final columns included: 1 2

'Coeff'	'Std.Err.'	'Status'	'P'
[1.4683]	[0.1213]	'In'	[2.6922e-007]
[0.6623]	[0.0459]	'In'	[5.0290e-008]
[0.2500]	[0.1847]	'Out'	[0.2089]
[-0.2365]	[0.1733]	'Out'	[0.2054]

The preceding two models, built from different initial models, use different subsets of the predictive terms. Terms 2 and 4, swapped in the two models, are highly correlated:

```
term2 = ingredients(:,2);
term4 = ingredients(:,4);
R = corrcoef(term2,term4)
R =
    1.0000    -0.9730
   -0.9730    1.0000
```

To compare the models, use the stats output of stepwisefit:

```
[betahat1,se1,pval1,inmodel1,stats1] = ...
    stepwisefit(ingredients,heat,...
    'penter',.05,'premove',0.10,...
```

stepwisefit

```
        'display','off');
[betahat2,se2,pval2,inmodel2,stats2] = ...
    stepwisefit(ingredients,heat,...
                'inmodel',initialModel,...
                'penter',.05,'premove',0.10,...
                'display','off');

RMSE1 = stats1.rmse
RMSE1 =
    2.7343
RMSE2 = stats2.rmse
RMSE2 =
    2.4063
```

The second model has a lower Root Mean Square Error (RMSE).

References

[1] Draper, N. R., and H. Smith. *Applied Regression Analysis*. Hoboken, NJ: Wiley-Interscience, 1998. pp. 307–312.

See Also

[stepwise](#) | [addedvarplot](#) | [regress](#)

Purpose Subscripted assignment for categorical array

Syntax `A = subsasgn(A,S,B)`

Description `A = subsasgn(A,S,B)` is called for the syntax `A(i)=B`. `S` is a structure array with the fields:

`type` String containing '()' specifying the subscript type. Only parenthesis subscripting is allowed.

`subs` Cell array or string containing the actual subscripts.

See Also `categorical` | `subsref`

classregtree.subsasgn

Purpose Subscripted reference for classregtree object

Syntax

Description Subscript assignment is not allowed for a classregtree object.

See Also classregtree

Purpose

Subscripted assignment to dataset array

Description

$A = \text{subsasgn}(A, S, B)$ is called for the syntax $A(i, j) = B$, $A\{i, j\} = B$, or $A.\text{var} = B$ when A is a dataset array. S is a structure array with the fields:

type	String containing '()', '{}', or '.' specifying the subscript type.
subs	Cell array or string containing the actual subscripts.

$A(i, j) = B$ assigns the contents of the dataset array B to a subset of the observations and variables in the dataset array A . i and j are one of the following types:

- positive integers
- vectors of positive integers
- observation/variable names
- cell arrays containing one or more observation/variable names
- logical vectors

The assignment does not use observation names, variable names, or any other properties of B to modify properties of A ; however properties of A are extended with default values if the assignment expands the number of observations or variables in A . Elements of B are assigned into A by position, not by matching names.

$A\{i, j\} = B$ assigns the value B into an element of the dataset array A . i and J are positive integers, or logical vectors. Cell indexing cannot assign into multiple dataset elements, that is, the subscripts i and j must each refer to only a single observation or variable. B is cast to the type of the target variable if necessary. If the dataset element already exists, $A\{i, j\}$ may also be followed by further subscripting as supported by the variable.

For dataset variables that are cell arrays, assignments such as `A{1, 'CellVar'} = B` assign into the contents of the target dataset element in the same way that `{}`-indexing of an ordinary cell array does.

For dataset variables that are n-D arrays, i.e., each observation is a matrix or array, an assignment such as `A{1, 'ArrayVar'} = B` assigns into the second and following dimensions of the target dataset element, i.e., the assignment adds a leading singleton dimension to `B` to account for the observation dimension of the dataset variable.

`A.var = B` or `A.(varname) = B` assigns `B` to a dataset variable. `var` is a variable name literal, or `varname` is a character variable containing a variable name. If the dataset variable already exists, the assignment completely replaces that variable. To assign into an element of the variable, `A.var` or `A.(varname)` may be followed by further subscripting as supported by the variable. In particular, `A.var(obsnames, ...)` = `B` and `A.var{obsnames, ...}` = `B` (when supported by `var`) provide assignment into a dataset variable using observation names.

`A.properties.propertyname = P` assigns to a dataset property. `propertyname` is one of the following:

- 'ObsNames'
- 'VarNames'
- 'Description'
- 'Units'
- 'DimNames'
- 'UserData'
- 'VarDescription'

To assign into an element of the property, `A.properties.propertyname` may also be followed by further subscripting as supported by the property.

You cannot assign multiple values into dataset variables or properties using assignments such as `[A.CellVar{1:2}] = B`,

[A.StructVar(1:2).field] = B, or [A.Properties.ObsNames{1:2}] = B. Use multiple assignments of the form A.CellVar{1} = B instead.

Similarly, if a dataset variable is a cell array with multiple columns or is an n-D cell array, then the contents of that variable for a single observation consists of multiple cells, and you cannot assign to all of them using the syntax A{1, 'CellVar'} = B. Use multiple assignments of the form [A.CellVar{1,1}] = B instead.

See Also

dataset | set | subsref

gmdistribution.subsasgn

- Purpose** Subscripted reference for Gaussian mixture distribution object
- Description** Subscript assignment is not allowed for gmdistribution objects.
- See Also** gmdistribution

Purpose Subscripted reference for NaiveBayes object

Description Subscript assignment is not allowed for a NaiveBayes object.

categorical.subsindex

Purpose Subscript index for categorical array

Syntax `I = subsindex(A)`

Description `I = subsindex(A)` is called for the syntax '`X(A)`' when `A` is a categorical array and `X` is one of the built-in types (most commonly 'double'). `subsindex` returns the internal categorical level codes of `A` converted to zero-based integer indices. `subsindex` is invoked separately on all the subscripts in an expression such as `X(A,B)`.

Examples

```
load fisheriris
a = ordinal(species,[],unique(species));
colmeans = grpstats(meas,a,@mean);
residuals = meas - colmeans(a,:);
```

See Also `categorical` | `double`

Purpose Subscripted reference for classregtree object

Syntax `B = subsref(T,S)`

Description `B = subsref(T,S)` is called for the syntax `T(X)` when `T` is a classregtree object. `S` is a structure array with the fields:

`type` String containing '()', '{}', or '.' specifying the subscript type.

`subs` Cell array or string containing the actual subscripts.

`[...] = T(...)` invokes the `eval` method for the tree `T`.

See Also classregtree | eval

categorical.subsref

Purpose Subscripted reference for categorical array

Syntax `A = subsref(A,S,B)`

Description `A = subsref(A,S,B)` is called for the syntax `A(I)=B`. `S` is a structure array with the fields:

`type` String containing '()' specifying the subscript type. Only parenthesis subscripting is allowed.

`subs` Cell array or string containing the actual subscripts.

See Also `categorical` | `subsasgn`

Purpose Subscripted reference for dataset array

Syntax `B = subsref(A,S)`

Description `B = subsref(A,S)` is called for the syntax `A(i,j)`, `A{i,j}`, or `A.var` when `A` is a dataset array. `S` is a structure array with the fields:

<code>type</code>	String containing '()', '{}', or '.' specifying the subscript type.
<code>subs</code>	Cell array or string containing the actual subscripts.

`B = A(i,j)` returns a dataset array that contains a subset of the observations and variables in the dataset array `A`. `i` and `j` are one of the following types:

- positive integers
- vectors of positive integers
- observation/variable names
- cell arrays containing one or more observation/variable names
- logical vectors

`B` contains the same property values as `A`, subsetted for observations or variables where appropriate.

`B = A{i,j}` returns an element of a dataset variable. `i` and `j` are positive integers, or logical vectors. Cell indexing cannot return multiple dataset elements, that is, the subscripts `i` and `j` must each refer to only a single observation or variable. `A{i,j}` may also be followed by further subscripting as supported by the variable.

For dataset variables that are cell arrays, expressions such as `A{1, 'CellVar'}` return the contents of the referenced dataset element in the same way that {}-indexing on an ordinary cell array does. If the dataset variable is a single column of cells, the contents of a single cell

dataset.subsref

is returned. If the dataset variable has multiple columns or is n-D, multiple outputs containing the contents of multiple cells are returned.

For dataset variables that are n-D arrays, i.e., each observation is a matrix or an array, expressions such as `A{1, 'ArrayVar'}` return `A.ArrayVar(1, :, ...)` with the leading singleton dimension squeezed out.

`B = A.var` or `A.(varname)` returns a dataset variable. `var` is a variable name literal, or `varname` is a character variable containing a variable name. `A.var` or `A.(varname)` may also be followed by further subscripting as supported by the variable. In particular, `A.var(obsnames, ...)` and `A.var{obsnames, ...}` (when supported by `var`) provide subscripting into a dataset variable using observation names.

`P = A.Properties.propertyname` returns a dataset property. `propertyname` is one of the following:

- 'ObsNames'
- 'VarNames'
- 'Description'
- 'Units'
- 'DimNames'
- 'UserData'
- 'VarDescription'

`A.properties.propertyname` may also be followed by further subscripting as supported by the property.

Limitations

Subscripting expressions such as `A.CellVar{1:2}`, `A.StructVar(1:2).field`, or `A.Properties.ObsNames{1:2}` are valid, but result in `subsref` returning multiple outputs in the form of a comma-separated list. If you explicitly assign to output

arguments on the left-hand side of an assignment, for example, `[cellval1, cellval2] = A.CellVar{1:2}`, those variables will receive the corresponding values. However, if there are no output arguments, only the first output in the comma-separated list is returned.

Similarly, if a dataset variable is a cell array with multiple columns or is an n-D cell array, then subscripting expressions such as `A{1, 'CellVar'}` result in `subsref` returning the contents of multiple cells. You should explicitly assign to output arguments on the left-hand side of an assignment, for example, `[cellval1, cellval2] = A{1, 'CellVar'}`.

See Also

[dataset](#) | [set](#) | [subsasgn](#)

gmdistribution.subsref

Purpose Subscripted reference for Gaussian mixture distribution object

Syntax `B = subsref(T,S)`

Description `B = subsref(T,S)` is called for the syntax `T(X)` when `T` is a `gmdistribution` object. `S` is a structure array with the following fields:

<code>type</code>	String containing '()', '{}', or '.' specifying the subscript type.
<code>subs</code>	Cell array or string containing the actual subscripts.

See Also `gmdistribution`

Purpose Subscripted reference for NaiveBayes object

Syntax `b = subsref(nb,s)`

Description `b = subsref(nb,s)` is called for the syntax `nb(s)` when `nb` is a NaiveBayes object. `S` is a structure array with the fields:

<code>type</code>	string containing <code>'()'</code> , <code>'{'</code> , or <code>'.'</code> specifying the subscript type.
<code>subs</code>	Cell array or string containing the actual subscripts.

grandset.subsref

Purpose Subscripted reference for grandset

Syntax
`x = p(i,j)`
`x = subsref(p,s)`

Description `x = p(i,j)` returns a matrix that contains a subset of the points from the point set `p`. The indices in `i` select points from the set and the indices in `j` select columns from those points. `i` and `j` are vector of positive integers or logical vectors. A colon used as a subscript, as in `p(i,:)`, indicates the entire row (or column).

`x = subsref(p,s)` is called for the syntax `p(i)`, `p{i}`, or `p.i`. `s` is a structure array with the fields:

`type` string containing `'()'`, `'{}'`, or `'.'` specifying the subscript type.

`subs` Cell array or string containing the actual subscripts.

Examples

Command	Returns
<code>p = sobolset(5);</code>	The fifth point
<code>x = p(1:10,:)</code>	All columns of the first 10 points
<code>x = p(end,1)</code>	The first column of the last point
<code>x = p([1,4,5], :)</code>	Points 1, 4, and 5

See Also grandset

Purpose Summary statistics for categorical array

Syntax

```
summary(A)  
C = summary(A)  
[C,labels] = summary(A)
```

Description `summary(A)` displays the number of elements in the categorical array `A` equal to each of the possible levels in `A`. If `A` contains any undefined elements, the output also includes the number of undefined elements.

`C = summary(A)` returns counts of the number of elements in the categorical array `A` equal to each of the possible levels in `A`. If `A` is a matrix or N -dimensional array, `C` is a matrix or array with rows corresponding to the levels of `A`. If `A` contains any undefined elements, `C` contains one more row than the number of levels of `A`, with the number of undefined elements in `c(end)` or `c(end,:)`.

`[C,labels] = summary(A)` also returns the list of categorical level labels corresponding to the counts in `C`.

Examples Count the number of patients in each age group in the data in `hospital.mat`:

```
load hospital  
edges = 0:10:100;  
labels = strcat(num2str((0:10:90)'),'%d'),{'s'});  
AgeGroup = ordinal(hospital.Age,labels,[],edges);  
[c,labels] = summary(AgeGroup);
```

```
Table = dataset({labels,'AgeGroup'},{c,'Count'});
```

```
Table(3:6,:)
```

```
ans =  
    AgeGroup    Count  
    '20s'       15  
    '30s'       41  
    '40s'       42  
    '50s'        2
```

categorical.summary

See Also

`islevel` | `ismember` | `levelcounts`

Purpose Print summary of dataset array

Syntax
`summary(A)`
`s = summary(A)`

Description `summary(A)` prints a summary of a dataset array and the variables that it contains.

`s = summary(A)` returns a scalar structure `s` that contains a summary of the dataset `A` and the variables that `A` contains. For more information on the fields in `s`, see Outputs.

Summary information depends on the type of the variables in the data set:

- For numerical variables, `summary` computes a five-number summary of the data, giving the minimum, the first quartile, the median, the third quartile, and the maximum.
- For logical variables, `summary` counts the number of `true`s and `false`s in the data.
- For categorical variables, `summary` counts the number of data at each level.

Output Arguments

The following list describes the fields in the structure `s`:

- **Description** — A character array containing the dataset description.
- **Variables** — A structure array with one element for each dataset variable in `A`. Each element has the following fields:
 - **Name** — A character string containing the name of the variable.
 - **Description** — A character string containing the variable's description.
 - **Units** — A character string containing the variable's units.
 - **Size** — A numeric vector containing the size of the variable.

dataset.summary

- **Class** — A character string containing the class of the variable.
- **Data** — A scalar structure containing the following fields.

For numeric variables:

- **Probabilities** — A numeric vector containing the probabilities [0.0 .25 .50 .75 1.0] and NaN (if any are present in the corresponding dataset variable).
- **Quantiles** — A numeric vector containing the values that correspond to 'Probabilities' for the corresponding dataset variable, and a count of NaNs (if any are present).

For logical variables:

- **Values** — The logical vector [true false].
- **Counts** — A numeric vector of counts for each logical value.

For categorical variables:

- **Levels** — A cell array containing the labels for each level of the corresponding dataset variable.
- **Counts** — A numeric vector of counts for each level.

'Data' is empty if variable is not numeric, categorical, or logical. If a dataset variable has more than one column, then the corresponding 'Quantiles' or 'Counts' field is a matrix or an array.

Examples

Summarize Fisher's iris data:

```
load fisheriris
species = nominal(species);
data = dataset(species,meas);
summary(data)
species: [150x1 nominal]
      setosa  versicolor  virginica
      50         50         50
```

```
meas: [150x4 double]
  min      4.3000      2      1      0.1000
  1st Q    5.1000    2.8000    1.6000    0.3000
  median   5.8000      3      4.3500    1.3000
  3rd Q    6.4000    3.3000    5.1000    1.8000
  max      7.9000    4.4000    6.9000    2.5000
```

Summarize the data in hospital.mat:

```
load hospital
summary(hospital)
```

Dataset array created from the data file hospital.dat.

The first column of the file ("id") is used for observation names. Other columns ("sex" and "smoke") have been converted from their original coded values into categorical and logical variables. Two sets of columns ("sys" and "dia", "trial1" through "trial4") have been combined into single variables with multivariate observations. Column headers have been replaced with more descriptive variable names. Units have been added where appropriate.

```
LastName: [100x1 cell string]
```

```
Sex: [100x1 nominal]
```

```
  Female      Male
    53         47
```

```
Age: [100x1 double, Units = Yrs]
```

```
  min      1st Q      median      3rd Q      max
    25         32         39         44         50
```

```
Weight: [100x1 double, Units = Lbs]
```

```
  min      1st Q      median      3rd Q      max
   111    130.5000    142.5000    180.5000    202
```

dataset.summary

Smoker: [100x1 logical]

true	false
34	66

BloodPressure: [100x2 double, Units = mm Hg]

Systolic/Diastolic

min	109	68
1st Q	117.5000	77.5000
median	122	81.5000
3rd Q	127.5000	89
max	138	99

Trials: [100x1 cell, Units = Counts]

From zero to four measurement trials performed

See Also

get | set | grpstats

Purpose

Read-only structure containing information about support of ProbDist object

Description

Support is a read-only property of the ProbDist class. Support is a structure containing information about the support of a ProbDist object. It includes the following fields:

- `range`
- `closedbound`
- `iscontinuous`

Values

The values for the three fields in the structure are:

- `range` — A two-element vector $[L, U]$, such that all of the probability is contained from L to U .
- `closedbound` — A two-element logical vector indicating whether the corresponding range endpoint is included. Possible values for each endpoint are 1 (true) or 0 (false).
- `iscontinuous` — A logical value indicates if the distribution takes values on the entire interval from L to U (true), or if it takes only integer values within this range (false). Possible values are 1 (true) or 0 (false).

Use this information to view and compare information about the support of distributions.

struct2dataset

Purpose Convert structure array to dataset array

Syntax
`ds = struct2dataset(S)`
`ds = struct2dataset(S,Name,Value)`

Description `ds = struct2dataset(S)` converts a structure array to a dataset array.

`ds = struct2dataset(S,Name,Value)` performs the conversion using additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

S - Input structure array

structure array

Input structure array to convert to a dataset array, specified as a scalar structure array with N fields, each with M rows, or a nonscalar M -by-1 structure array with N fields.

Data Types

struct

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

Example: `'ReadObsNames','myField'` specifies that the structure field, `myField`, contains observation names.

ReadObsNames - Name of structure field containing observation names for dataset array

`false` (default) | string

Name of structure field containing observation names for the output dataset array, specified as the comma-separated pair consisting of `'ReadObsNames'` and a string containing a field name from

the input structure array, `S`. When you specify a field name, `struct2dataset` uses that field to create observation names, and sets `ds.Properties.DimNames` equal to `{ReadObsNames, 'Variables'}`.

For example, to specify that observation names are in the structure field, `Names`, use

Example: `'ReadObsNames', 'Names'`

By default, or if `ReadObsNames` is equal to `false`, `struct2dataset` does not create observation names unless you specify names using the name-value pair argument `ObsNames`.

ObsNames - Observation names for dataset array

cell array of strings

Observation names for the output dataset array, specified as the comma-separated pair consisting of `'ObsNames'` and a cell array of strings containing observation names. The names do not need to be valid MATLAB identifiers, but they must be unique.

AsScalar - Indicator for how to treat scalar structure

`false` | `true`

Indicator for how to treat a scalar input structure array, specified as the comma-separated pair consisting of `'AsScalar'` and either `true` or `false`. The default value is `true` if `S` is a scalar structure array, and `false` otherwise.

By default, `struct2dataset` converts a scalar structure array with N fields, each with M rows, into an M -by- N dataset array.

If instead you set `AsScalar` equal to `false` for a scalar input structure array, then `struct2dataset` converts `S` to a dataset array with N observations.

Output Arguments

ds - Output dataset array

dataset array

Output dataset array, returned by default with M observations and N variables.

struct2dataset

- If **S** is a scalar structure array with N fields, each with M rows, then **ds** is an M -by- N dataset array.
- If **S** is a nonscalar M -by-1 structure array with N fields, then **ds** is an M -by- N dataset array.
- If **S** is a scalar structure array with N fields, each with M rows, and **AsScalar** is set equal to `false`, then **ds** is a dataset array with N observations.

Examples

Convert Scalar Structure Array to Dataset Array

Convert a scalar structure array to a dataset array using the default options.

Create a structure array to convert.

```
S.Name = {'CLARK'; 'BROWN'; 'MARTIN'};  
S.Gender = {'M'; 'F'; 'M'};  
S.SystolicBP = [124; 122; 130];  
S.DiastolicBP = [93; 80; 92];  
S
```

```
S =
```

```
      Name: {3x1 cell}  
      Gender: {3x1 cell}  
      SystolicBP: [3x1 double]  
      DiastolicBP: [3x1 double]
```

The scalar structure array has four fields, each with three rows.

Convert the structure array to a dataset array.

```
ds = struct2dataset(S)
```

```
ds =
```

```
      Name      Gender      SystolicBP      DiastolicBP  
'CLARK'      'M'          124          93
```

```
'BROWN'      'F'      122      80
'MARTIN'     'M'      130      92
```

The structure field names in `S` become the variable names in the output dataset array. The size of `ds` is 3-by-4.

Convert Nonscalar Structure Array to Dataset Array

Convert a nonscalar structure array to a dataset array, using one of the structure fields for observation names.

Create a nonscalar structure array to convert.

```
S(1,1).Name = 'CLARK';
S(1,1).Gender = 'M';
S(1,1).SystolicBP = 124;
S(1,1).DiastolicBP = 93;
```

```
S(2,1).Name = 'BROWN';
S(2,1).Gender = 'F';
S(2,1).SystolicBP = 122;
S(2,1).DiastolicBP = 80;
```

```
S(3,1).Name = 'MARTIN';
S(3,1).Gender = 'M';
S(3,1).SystolicBP = 130;
S(3,1).DiastolicBP = 92;
```

```
S
```

```
S =
```

```
3x1 struct array with fields:
    Name
    Gender
    SystolicBP
    DiastolicBP
```

This is a 3-by-1 structure array with 4 fields.

struct2dataset

Convert the structure array to a dataset array, using the Name field for observation names.

```
ds = struct2dataset(S, 'ReadObsNames', 'Name')
```

```
ds =
```

	Gender	SystolicBP	DiastolicBP
CLARK	'M'	124	93
BROWN	'F'	122	80
MARTIN	'M'	130	92

The size of `ds` is 3-by-3 because the structure field `Name` is used for observation names, and not as a dataset array variable.

```
ds.Properties.DimNames
```

```
ans =
```

```
    'Name'    'Variables'
```

```
ds.Properties.ObsNames
```

```
ans =
```

```
    'CLARK'  
    'BROWN'  
    'MARTIN'
```

See Also

[dataset](#) | [dataset2struct](#) | [cell2dataset](#)

Related Examples

- “Create a Dataset Array from Workspace Variables” on page 2-86
- “Create a Dataset Array from a File” on page 2-92

Concepts

- “Dataset Arrays” on page 2-156

Purpose

Interactive contour plot

Syntax

```
surfht(Z)  
surfht(x,y,Z)
```

Description

`surfht(Z)` is an interactive contour plot of the matrix Z treating the values in Z as height above the plane. The x -values are the column indices of Z while the y -values are the row indices of Z .

`surfht(x,y,Z)` where x and y are vectors specify the x and y -axes on the contour plot. The length of x must match the number of columns in Z , and the length of y must match the number of rows in Z .

There are vertical and horizontal reference lines on the plot whose intersection defines the current x value and y value. You can drag these dotted white reference lines and watch the interpolated z value (at the top of the plot) update simultaneously. Alternatively, you can get a specific interpolated z value by typing the x value and y value into editable text fields on the x -axis and y -axis respectively.

classregtree.surrcutcategories

Purpose Categories used for surrogate splits in decision tree

Syntax `C = surrcutcategories(T)`
`C = surrcutcategories(T,J)`

Description `C = surrcutcategories(T)` returns an n -element cell array `C` of the categories used for surrogate splits in the decision tree `T`, where n is the number of nodes in the tree. For each node `K`, `C{K}` is a cell array. The length of `C{K}` is equal to the number of surrogate predictors found at this node. Every element of `C{K}` is either an empty string for a continuous surrogate predictor or a two-element cell array with categories for a categorical surrogate predictor. The first element of this two-element cell array lists categories assigned to the left child by this surrogate split and the second element of this two-element cell array lists categories assigned to the right child by this surrogate split. The order of the surrogate split variables at each node is matched to the order of variables returned by `surrcutvar`. The optimal-split variable at this node is not included. For non-branch (leaf) nodes, `C` contains an empty cell.

`C = surrcutcategories(T,J)` takes an array `J` of node numbers and returns the categories for the specified nodes.

See Also `classregtree` | `surrcutvar` | `cutcategories` | `surrcuttype` | `surrcutpoint`

Purpose Numeric cutpoint assignments used for surrogate splits in decision tree

Syntax `V = surrcutflip(T)`
`V = surrcutflip(T,J)`

Description `V = surrcutflip(T)` returns an n -element cell array V of the numeric cut assignments used for surrogate splits in the decision tree T , where n is the number of nodes in the tree. For each node K , $V\{K\}$ is a numeric vector. The length of $V\{K\}$ is equal to the number of surrogate predictors found at this node. Every element of $V\{K\}$ is either zero for a categorical surrogate predictor or a numeric cut assignment for a continuous surrogate predictor. The numeric cut assignment can be either -1 or $+1$. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and the cut assignment for this surrogate split is $+1$, or if $Z \geq C$ and the cut assignment for this surrogate split is -1 . Similarly, the right child is chosen if $Z \geq C$ and the cut assignment for this surrogate split is $+1$, or if $Z < C$ and the cut assignment for this surrogate split is -1 . The order of the surrogate split variables at each node is matched to the order of variables returned by `surrcutvar`. The optimal-split variable at this node is not included. For non-branch (leaf) nodes, V contains an empty array.

`V = surrcutflip(T,J)` takes an array J of node numbers and returns the cutpoint assignments for the specified nodes.

See Also `classregtree` | `surrcutvar` | `surrcutcategories` | `surrcuttype` | `surrcutpoint` | `cutpoint`

classregtree.surrcutpoint

Purpose Cutpoints used for surrogate splits in decision tree

Syntax
`V = surrcutpoint(T)`
`V = surrcutpoint(T,J)`

Description `V = surrcutpoint(T)` returns an n -element cell array V of the numeric values used for surrogate splits in the decision tree T , where n is the number of nodes in the tree. For each node K , $V\{K\}$ is a numeric vector. The length of $V\{K\}$ is equal to the number of surrogate predictors found at this node. Every element of $V\{K\}$ is either either `NaN` for a categorical surrogate predictor or a numeric cut for a continuous surrogate predictor. For every surrogate split with a numeric cut C based on a continuous predictor variable Z , the left child is chosen if $Z < C$ and `surrcutflip` for this surrogate split is `-1`. Similarly, the right child is chosen if $Z \geq C$ and `surrcutflip` for this surrogate split is `+1`, or if $Z < C$ and `surrcutflip` for this surrogate split is `-1`. The order of the surrogate split variables at each node is matched to the order of variables returned by `surrcutvar`. The optimal-split variable at this node is not included. For non-branch (leaf) nodes, V contains an empty cell.

`V = surrcutpoint(T,J)` takes an array J of node numbers and returns the cutpoint assignments for the specified nodes.

See Also `classregtree` | `surrcutvar` | `surrcutcategories` | `surrcuttype` | `surrcutflip` | `cutpoint`

Purpose

Types of surrogate splits used at branches in decision tree

Syntax

```
C = surrcuttype(T)
C = surrcuttype(T,J)
```

Description

`C = surrcuttype(T)` returns an n -element cell array `C` indicating types of surrogate splits at each node in the tree `T`, where n is the number of nodes in the tree. For each node `K`, `C{K}` is a cell array with the types of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The order of the surrogate split variables at each node is matched to the order of variables returned by `surrcutvar`. The optimal-split variable at this node is not included. For non-branch (leaf) nodes, `C` contains an empty cell. A surrogate split type can be either 'continuous' if the cut is defined in the form $Z < V$ for a variable `Z` and cutpoint `V` or 'categorical' if the cut is defined by whether `Z` takes a value in a set of categories.

`C = surrcuttype(T,J)` takes an array `J` of node numbers and returns the cut types for the specified nodes.

See Also

`classregtree` | `numnodes` | `cuttype` | `surrcutvar`

classregtree.surrcutvar

Purpose Variables used for surrogate splits in decision tree

Syntax
`V = surrcutvar(T)`
`V = surrcutvar(T,J)`
`[V,NUM] = surrcutvar(...)`

Description `V = surrcutvar(T)` returns an n -element cell array `V` of the names of the variables used for surrogate splits in each node of the tree `T`, where n is the number of nodes in the tree. Every element of `V` is a cell array with the names of the surrogate split variables at this node. The variables are sorted by the predictive measure of association with the optimal predictor in the descending order, and only variables with the positive predictive measure are included. The optimal-split variable at this node is not included. For non-branch (leaf) nodes, `V` contains an empty cell.

`V = surrcutvar(T,J)` takes an array `J` of node numbers and returns the cut types for the specified nodes.

`[V,NUM] = surrcutvar(...)` also returns a cell array `NUM` with indices for each variable.

See Also `classregtree` | `numnodes` | `children` | `cutvar`

Purpose	Predictive measure of association for surrogate splits in decision tree
Syntax	<code>A = surrvarassoc(T)</code> <code>A = surrvarassoc(T,J)</code>
Description	<p><code>A = surrvarassoc(T)</code> returns an n-element cell array A of the predictive measures of association for surrogate splits in the decision tree T, where n is the number of nodes in the tree. For each node K, $A\{K\}$ is a numeric vector. The length of $A\{K\}$ is equal to the number of surrogate predictors found at this node. Every element of $A\{K\}$ gives the predictive measure of association between the optimal split and this surrogate split. The order of the surrogate split variables at each node is matched to the order of variables returned by <code>surrvar</code>. The optimal-split variable at this node is not included. For non-branch (leaf) nodes, V contains an empty cell.</p> <p><code>A = surrvarassoc(T,J)</code> takes an array J of node numbers and returns the predictive measure of association for the specified nodes.</p>
See Also	<code>classregtree</code> <code>surrvarcategories</code> <code>surrvarcuttype</code> <code>surrvarcutflip</code> <code>surrvarcutpoint</code> <code>surrvarcutvar</code>

tabulate

Purpose Frequency table

Syntax TABLE = tabulate(x)
tabulate(x)

Description TABLE = tabulate(x) creates a frequency table of data in vector x. Information in TABLE is arranged as follows:

- 1st column — The unique values of x
- 2nd column — The number of instances of each value
- 3rd column — The percentage of each value

If x is a numeric array, TABLE is a numeric matrix. If the elements of x are nonnegative integers, TABLE includes 0 counts for integers between 1 and max(x) that do not appear in x.

If x is a categorical variable, character array, or cell array of strings, TABLE is a cell array.

tabulate(x) with no output arguments displays the table in the command window.

Examples

```
tabulate([1 2 4 4 3 4])
  Value  Count  Percent
     1     1    16.67%
     2     1    16.67%
     3     1    16.67%
     4     3    50.00%
```

See Also pareto

How To

- “Grouping Variables” on page 2-72

Purpose

Read tabular data from file

Syntax

```
[data,varnames,casenames] = tblread
[data,varnames,casenames] = tblread(filename)
[data,varnames,casenames] = tblread(filename,delimiter)
```

Description

[data,varnames,casenames] = tblread displays the File Open dialog box for interactive selection of a tabular data file. The file format has variable names in the first row, case names in the first column and data starting in the (2, 2) position. Outputs are:

- data — Numeric matrix with a value for each variable-case pair
- varnames — String matrix containing the variable names in the first row of the file
- casenames — String matrix containing the names of each case in the first column of the file

[data,varnames,casenames] = tblread(*filename*) allows command line specification of the name of a file in the current folder, or the complete path name of any file, using the string *filename*.

[data,varnames,casenames] = tblread(*filename,delimiter*) reads from the file using *delimiter* as the delimiting character. Accepted values for *delimiter* are:

- ' ' or 'space'
- '\t' or 'tab'
- ',' or 'comma'
- ';' or 'semi'
- '|' or 'bar'

The default value of *delimiter* is 'space'.

Examples

```
[data,varnames,casenames] = tblread('sat.dat')
data =
    470  530
```

tblread

520 480

varnames =

Male

Female

casenames =

Verbal

Quantitative

See Also

[tblwrite](#) | [tdfread](#) | [caseread](#)

Purpose Write tabular data to file

Syntax

```
tblwrite(data,varnames,casenames)
tblwrite(data,varnames,casenames,filename)
tblwrite(data,varnames,casenames,filename,delimiter)
```

Description `tblwrite(data,varnames,casenames)` displays the **File Open** dialog box for interactive specification of the tabular data output file. The file format has variable names in the first row, case names in the first column and data starting in the (2,2) position.

`varnames` is a string matrix containing the variable names. `casenames` is a string matrix containing the names of each case in the first column. `data` is a numeric matrix with a value for each variable-case pair.

`tblwrite(data,varnames,casenames,filename)` specifies a file in the current folder, or the complete path name of any file in the string `filename`.

`tblwrite(data,varnames,casenames,filename,delimiter)` writes to the file using `delimiter` as the delimiting character. The following table lists the accepted character values for `delimiter` and their equivalent string values.

Character	String
' '	'space'
'\t'	'tab'
','	'comma'
';'	'semi'
' '	'bar'

The default value of `delimiter` is 'space'.

Examples Continuing the example from `tblread`:

```
tblwrite(data,varnames,casenames,'sattest.dat')
```

tblwrite

```
type sattetst.dat
      Male Female
Verbal    470  530
Quantitative 520  480
```

See Also

`casewrite` | `tblread`

Purpose Student's t cumulative distribution function

Syntax $P = \text{tcdf}(X,V)$

Description $P = \text{tcdf}(X,V)$ computes Student's t cdf at each of the values in X using the corresponding degrees of freedom in V . X and V can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs.

The t cdf is

$$p = F(x|v) = \int_{-\infty}^x \frac{\Gamma\left(\frac{v+1}{2}\right)}{\Gamma\left(\frac{v}{2}\right)} \frac{1}{\sqrt{v\pi}} \frac{1}{\left(1 + \frac{t^2}{v}\right)^{\frac{v+1}{2}}} dt$$

The result, p , is the probability that a single observation from the t distribution with v degrees of freedom will fall in the interval $[-\infty, x)$.

Examples

```
mu = 1; % Population mean
sigma = 2; % Population standard deviation
n = 100; % Sample size
x = normrnd(mu,sigma,n,1); % Random sample from population
xbar = mean(x); % Sample mean
s = std(x); % Sample standard deviation
t = (xbar-mu)/(s/sqrt(n)) % t-statistic
t =
    0.2489
p = 1-tcdf(t,n-1) % Probability of larger t-statistic
p =
    0.4020
```

This probability is the same as the p value returned by a t -test of the null hypothesis that the sample comes from a normal population with mean μ :

tcdf

```
[h,ptest] = ttest(x,mu,0.05,'right')
h =
    0
ptest =
    0.4020
```

See Also

[cdf](#) | [tpdf](#) | [tinv](#) | [tstat](#) | [trnd](#)

How To

- “Student’s t Distribution” on page B-108

Purpose Read tab-delimited file

Syntax

```
tdfread
tdfread(filename)
tdfread(filename,delimiter)
s = tdfread(filename,...)
```

Description tdfread displays the **File Open** dialog box for interactive selection of a data file, then reads data from the file. The file should have variable names separated by tabs in the first row, and data values separated by tabs in the remaining rows. tdfread creates variables in the workspace, one for each column of the file. The variable names are taken from the first row of the file. If a column of the file contains only numeric data in the second and following rows, tdfread creates a double variable. Otherwise, tdfread creates a char variable. After all values are imported, tdfread displays information about the imported values using the format of the tdfread command.

tdfread(*filename*) allows command line specification of the name of a file in the current folder, or the complete path name of any file, using the string *filename*.

tdfread(*filename,delimiter*) indicates that the character specified by *delimiter* separates columns in the file. Accepted values for *delimiter* are:

- ' ' or 'space'
- '\t' or 'tab'
- ',' or 'comma'
- ';' or 'semi'
- '|' or 'bar'

The default delimiter is 'tab'.

s = tdfread(*filename,...*) returns a scalar structure s whose fields each contain a variable.

tdfread

Examples

The following displays the contents of the file `sat2.dat`:

```
type sat2.dat

Test,Gender,Score
Verbal,Male,470
Verbal,Female,530
Quantitative,Male,520
Quantitative,Female,480
```

The following creates the variables `Gender`, `Score`, and `Test` from the file `sat2.dat` and displays the contents of the MATLAB workspace:

```
tdfread('sat2.dat','(',')')

Name      Size      Bytes      Class      Attributes
Gender    4x6        48         char
Score     4x1        32         double
Test      4x12       96         char
```

See Also

`tblread` | `caseread`

ClassificationDiscriminant.template

Purpose

Discriminant analysis classifier template for ensemble

Syntax

```
t = ClassificationDiscriminant.template()
t = ClassificationDiscriminant.template(Name,Value)
```

Description

`t = ClassificationDiscriminant.template()` returns a learner template suitable to use in the `fitensemble` function.

`t = ClassificationDiscriminant.template(Name,Value)` creates a template with additional options specified by one or more `Name, Value` pair arguments.

Input Arguments

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name, Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (`' '`). You can specify several name and value pair arguments in any order as `Name1, Value1, ..., NameN, ValueN`.

delta

Threshold on linear coefficients, a nonnegative scalar. If a coefficient of `obj` has magnitude smaller than `delta`, `obj` sets this coefficient to 0, and so you can eliminate the corresponding predictor from the model. Set `delta` to a higher value to eliminate more predictors.

`delta` must be 0 for quadratic discriminant models.

Default: 0

discrimType

String specifying the discriminant type. Case-insensitive. One of:

- `'linear'`
- `'quadratic'`

ClassificationDiscriminant.template

- 'diagLinear'
- 'diagQuadratic'
- 'pseudoLinear'
- 'pseudoQuadratic'

Default: 'linear'

fillCoeffs

String, either 'on' or 'off', specifying whether to populate the Coeffs property in the classifier object. Setting to 'on' can be computationally intensive, especially when cross validating.

Default: 'on', except 'off' when cross validating

gamma

Parameter for regularizing the correlation matrix of predictors.

- Linear discriminant — Scalar from 0 to 1.
 - If you pass a value strictly between 0 and 1, `ClassificationDiscriminant.fit` sets the discriminant type to 'Linear'.
 - If you pass 0 for gamma and 'Linear' for `DiscrimType`, and if the correlation matrix is singular, `ClassificationDiscriminant.fit` sets gamma to the minimal value required for inverting the covariance matrix.
 - If you set gamma to 1, `ClassificationDiscriminant.fit` sets the discriminant type to 'diagLinear'.
- Quadratic discriminant — Either 0 or 1.
 - If you pass 0 for gamma and 'Quadratic' for `DiscrimType`, and if one of the classes has a singular covariance matrix, `ClassificationDiscriminant.fit` errors.

ClassificationDiscriminant.template

- If you set gamma to 1, `ClassificationDiscriminant.fit` sets the discriminant type to `'diagQuadratic'`.

SaveMemory

When `'on'`, `ClassificationDiscriminant.fit` does not store the full covariance matrix, but instead stores enough information to compute the matrix. The `predict` method computes the full covariance matrix for prediction, and does not store the matrix. When `'off'`, `ClassificationDiscriminant.fit` computes and stores the full covariance matrix in `obj`.

Set `SaveMemory` to `'on'` when `X` has thousands of predictors.

Default: `'off'`

Output Arguments

t

Discriminant analysis classification template suitable to use in the `fitensemble` function. In an ensemble, `t` specifies how to create the discriminant analysis classifier.

Examples

Discriminant analysis template for nondefault options

Create a nondefault discriminant analysis template for use in `fitensemble`.

Create a template for pseudolinear discriminant analysis.

```
t = ClassificationDiscriminant.template('discrimType','pseudoLinear')
```

```
t =
```

```
Fit template for classification Discriminant.  
classreg.learning.modelparams.DiscriminantParams  
Package: classreg.learning.modelparams
```

```
Properties:
```

```
DiscrimType: 'pseudoLinear'
```

ClassificationDiscriminant.template

```
Gamma: []  
Delta: []  
FillCoeffs: []  
SaveMemory: []  
Method: 'Discriminant'  
Type: 'classification'
```

Superclasses

You can use `t` for ensemble learning.

See Also

`ClassificationDiscriminant` | `fitensemble`

Purpose *k*-nearest neighbor classifier template for ensemble

Syntax
`t = ClassificationKNN.template()`
`t = ClassificationKNN.template(Name,Value)`

Description
`t = ClassificationKNN.template()` returns a learner template suitable to use in the `fitensemble` function.
`t = ClassificationKNN.template(Name,Value)` creates a template with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

BreakTies

String specifying the method `predict` uses to break ties if multiple classes have the same smallest cost. By default, ties occur when multiple classes have the same number of nearest points among the `K` nearest neighbors.

- 'nearest' — Use the class with the nearest neighbor among tied groups.
- 'random' — Use a random tiebreaker among tied groups.
- 'smallest' — Use the smallest index among tied groups.

Default: 'smallest'

BucketSize

ClassificationKNN.template

Maximum number of data points in the leaf node of the *kd*-tree. This argument is meaningful only when `NSMethod` is `'kdtree'`.

Default: 50

Cov

Positive definite matrix, the covariance matrix when computing the Mahalanobis distance. This argument is only valid when `'Distance'` is `'mahalanobis'`.

Default: `nancov(X)`

Distance

String or function handle specifying the distance metric. The allowable strings depend on the `NSMethod` parameter, which you set in `ClassificationKNN.fit`, and which exists as a field in `ModelParams`.

NSMethod	Distance Metric Names
<code>exhaustive</code>	Any distance metric of <code>ExhaustiveSearcher</code>
<code>kdtree</code>	<code>'cityblock'</code> , <code>'chebychev'</code> , <code>'euclidean'</code> , or <code>'minkowski'</code>

For definitions, see “Distance Metrics” on page 13-9.

The distance metrics of `ExhaustiveSearcher`:

Value	Description
<code>'cityblock'</code>	City block distance.
<code>'chebychev'</code>	Chebychev distance (maximum coordinate difference).
<code>'correlation'</code>	One minus the sample linear correlation between observations (treated as sequences of values).

Value	Description
'cosine'	One minus the cosine of the included angle between observations (treated as vectors).
'euclidean'	Euclidean distance.
'hamming'	Hamming distance, percentage of coordinates that differ.
'jaccard'	One minus the Jaccard coefficient, the percentage of nonzero coordinates that differ.
'mahalanobis'	Mahalanobis distance, computed using a positive definite covariance matrix C . The default value of C is the sample covariance matrix of X , as computed by <code>nancov(X)</code> . To specify a different value for C , use the ' Cov ' name-value pair.
'minkowski'	Minkowski distance. The default exponent is 2. To specify a different exponent, use the ' P ' name-value pair.
'seuclidean'	Standardized Euclidean distance. Each coordinate difference between X and a query point is scaled, meaning divided by a scale value S . The default value of S is the standard deviation computed from X , <code>S = nanstd(X)</code> . To specify another value for S , use the Scale name-value pair.

ClassificationKNN.template

Value	Description
'spearman'	One minus the sample Spearman's rank correlation between observations (treated as sequences of values).
@ <i>distfun</i>	Distance function handle. <i>distfun</i> has the form <pre>function D2 = DISTFUN(ZI,ZJ) % calculation of distance ...</pre> where <ul style="list-style-type: none">• ZI is a 1-by-N vector containing one row of X or Y.• ZJ is an M2-by-N matrix containing multiple rows of X or Y.• D2 is an M2-by-1 vector of distances, and D2(k) is the distance between observations ZI and ZJ(J, :).

Default: 'euclidean', except the default is 'hamming' when CategoricalPredictors is 'all'

DistanceWeight

String or function handle specifying the distance weighting function.

DistanceWeight	Meaning
'equal'	No weighting
'inverse'	Weight is 1/distance

DistanceWeight	Meaning
'squareinverse'	Weight is $1/\text{distance}^2$
@fcn	<i>fcn</i> is a function that accepts a matrix of nonnegative distances, and returns a matrix the same size containing nonnegative distance weights. For example, 'squareinverse' is equivalent to $@(d)d.^{-2}$.

Default: 'equal'

Exponent

Positive scalar specifying the exponent of Minkowski distance. This argument is only valid when 'Distance' is 'minkowski'.

Default: 2

IncludeTies

Logical value indicating whether predict includes all the neighbors whose distance values are equal to the Kth smallest distance. If IncludeTies is true, predict includes all these neighbors. Otherwise, predict uses exactly K neighbors.

Default: false

NSMethod

String specifying the nearest neighbor search method:

- 'kdtree' — Create and use a *kd*-tree to find nearest neighbors. 'kdtree' is valid when the distance metric is one of the following:
 - 'euclidean'
 - 'cityblock'

ClassificationKNN.template

- 'minkowski'
- 'chebyshev'
- 'exhaustive' — Use the exhaustive search algorithm. The distance values from all points in X to each point in Y are computed to find nearest neighbors.

Default: 'kdtree' when X has 10 or fewer columns, X is not sparse, and the distance metric is a 'kdtree' type; otherwise, 'exhaustive'

NumNeighbors

Positive integer specifying the number of nearest neighbors in X to find for classifying each point when predicting.

Default: 1

Scale

Vector containing nonnegative values, with length equal to the number of columns in X . Each coordinate difference between X and a query point is scaled by the corresponding element of `Scale`. This argument is only valid when 'Distance' is 'seuclidean'.

Default: nanstd(X)

Output Arguments

t

K -nearest neighbor classification template suitable to use in the `fitensemble` function. In an ensemble, `t` specifies how to create the KNN classifier.

Examples

KNN template for nondefault options

Create a nondefault k -nearest neighbor template for use in `fitensemble`.

Create a template for 5-nearest neighbor search.

```
t = ClassificationKNN.template('NumNeighbors',5)
```

```
t =
```

```
Fit template for classification KNN.
```

```
classreg.learning.modelparams.KNNParams
```

```
Package: classreg.learning.modelparams
```

```
Properties:
```

```
  NumNeighbors: 5
```

```
  NSMethod: ''
```

```
  Distance: ''
```

```
  BucketSize: []
```

```
  IncludeTies: ''
```

```
  DistanceWeight: []
```

```
  BreakTies: []
```

```
  Exponent: []
```

```
  Cov: []
```

```
  Scale: []
```

```
  Method: 'KNN'
```

```
  Type: 'classification'
```

```
Superclasses
```

You can use `t` for ensemble learning.

See Also

[ClassificationKNN](#) | [fitensemble](#)

Related Examples

- “Random Subspace Classification” on page 13-114

ClassificationTree.template

Purpose Create classification template

Syntax
`t = ClassificationTree.template`
`t = ClassificationTree.template(Name,Value)`

Description
`t = ClassificationTree.template` returns a learner template suitable to use in the `fitensemble` function.
`t = ClassificationTree.template(Name,Value)` creates a template with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

MergeLeaves

String that specifies whether to merge leaves after the tree is grown. Values are 'on' or 'off'.

When 'on', `ClassificationTree` merges leaves that originate from the same parent node, and that give a sum of risk values greater or equal to the risk associated with the parent node. When 'off', `ClassificationTree` does not merge leaves.

Default: 'off'

MinLeaf

Each leaf has at least `MinLeaf` observations per tree leaf. If you supply both `MinParent` and `MinLeaf`, `ClassificationTree` uses the setting that gives larger leaves: `MinParent=max(MinParent,2*MinLeaf)`.

Default: Half the number of training observations for boosting, 1 for bagging

MinParent

Each branch node in the tree has at least `MinParent` observations. If you supply both `MinParent` and `MinLeaf`, `ClassificationTree` uses the setting that gives larger leaves: `MinParent=max(MinParent,2*MinLeaf)`.

Default: Number of training observations for boosting, 2 for bagging

NVarToSample

Number of predictors to select at random for each split. Can be a positive integer or 'all', which means use all available predictors.

Default: 'all' for boosting, square root of number of predictors for bagging

Prune

When 'on', `ClassificationTree` grows the classification tree and computes the optimal sequence of pruned subtrees. When 'off' `ClassificationTree` grows the tree without pruning.

Default: 'off'

PruneCriterion

String with the pruning criterion, either 'error' or 'impurity'.

Default: 'error'

SplitCriterion

ClassificationTree.template

Criterion for choosing a split. One of 'gdi' (Gini's diversity index), 'twoing' for the twoing rule, or 'deviance' for maximum deviance reduction (also known as cross entropy).

Default: 'gdi'

Surrogate

String describing whether to find surrogate decision splits at each branch node. This setting improves the accuracy of predictions for data with missing values. The setting also enables you to compute measures of predictive association between predictors. This setting can use much time and memory. Values are 'on' or 'off'.

Default: 'off'

Output Arguments

t

Classification tree template suitable to use in the `fitensemble` function. In an ensemble, `t` specifies how to grow the classification trees.

Examples

Create a classification template with surrogate splits, and train an ensemble for the Fisher iris model with the template:

```
t = ClassificationTree.template('surrogate','on');
load fisheriris
ens = fitensemble(meas,species,'AdaBoostM2',100,t);
```

See Also

[ClassificationTree](#) | [ClassificationTree.fit](#) | [fitensemble](#)

Purpose

Create regression template

Syntax

```
t = RegressionTree.template  
t = RegressionTree.template(Name,Value)
```

Description

`t = RegressionTree.template` returns a learner template suitable to use in the `fitensemble` function.

`t = RegressionTree.template(Name,Value)` creates a template with additional options specified by one or more `Name,Value` pair arguments. You can specify several name-value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

Input Arguments

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1, ...,NameN,ValueN`.

MergeLeaves

String that specifies whether to merge leaves after the tree is grown. Values are 'on' or 'off'.

When 'on', `RegressionTree` merges leaves that originate from the same parent node, and that give a sum of risk values greater or equal to the risk associated with the parent node. When 'off', `RegressionTree` does not merge leaves.

Default: 'off'

MinLeaf

Each leaf has at least `MinLeaf` observations per tree leaf. If you supply both `MinParent` and `MinLeaf`, `RegressionTree` uses the setting that gives larger leaves: `MinParent=max(MinParent,2*MinLeaf)`.

RegressionTree.template

Default: Half the number of training observations for boosting, 5 for bagging

MinParent

Each branch node in the tree has at least `MinParent` observations. If you supply both `MinParent` and `MinLeaf`, `RegressionTree` uses the setting that gives larger leaves: $\text{MinParent} = \max(\text{MinParent}, 2 * \text{MinLeaf})$.

Default: Number of training observations for boosting, 10 for bagging

NVarToSample

Number of predictors to select at random for each split. Can be a positive integer or 'all', which means use all available predictors.

Default: 'all' for boosting, one third of the number of predictors for bagging

Prune

When 'on', `RegressionTree` grows the regression tree and computes the optimal sequence of pruned subtrees. When 'off' `RegressionTree` grows the tree without pruning.

Default: 'off'

Surrogate

String describing whether to find surrogate decision splits at each branch node. This setting improves the accuracy of predictions for data with missing values. The setting also enables you to compute measures of predictive association between predictors. This setting can use much time and memory. Values are 'on' or 'off'.

Default: 'off'

Output Arguments

t

Regression tree template suitable to use in the `fitensemble` function. In an ensemble, `t` specifies how to grow the regression trees.

Examples

Create a regression template with surrogate splits, and train an ensemble for the `carsmall` data with the template:

```
t = RegressionTree.template('surrogate','on');
load carsmall
X = [Acceleration Displacement Horsepower Weight];
ens = fitensemble(X,MPG,'LSBoost',100,t);
```

See Also

[RegressionTree](#) | [RegressionTree.fit](#) | [fitensemble](#)

classregtree.test

Purpose Error rate

Syntax

```
cost = test(t, 'resubstitution')
cost = test(t, 'test', X, y)
cost = test(t, 'crossvalidate', X, y)
[cost, secost, ntnodes, bestlevel] = test(...)
[...] = test(..., param1, val1, param2, val2, ...)
```

Description

`cost = test(t, 'resubstitution')` computes the cost of the tree `t` using a resubstitution method. `t` is a decision tree as created by `classregtree`. The cost of the tree is the sum over all terminal nodes of the estimated probability of a node times the cost of a node. If `t` is a classification tree, the cost of a node is the sum of the misclassification costs of the observations in that node. If `t` is a regression tree, the cost of a node is the average squared error over the observations in that node. `cost` is a vector of cost values for each subtree in the optimal pruning sequence for `t`. The resubstitution cost is based on the same sample that was used to create the original tree, so it under estimates the likely cost of applying the tree to new data.

`cost = test(t, 'test', X, y)` uses the matrix of predictors `X` and the response vector `y` as a test sample, applies the decision tree `t` to that sample, and returns a vector `cost` of cost values computed for the test sample. `X` and `y` should not be the same as the learning sample, that is, the sample that was used to fit the tree `t`.

`cost = test(t, 'crossvalidate', X, y)` uses 10-fold cross-validation to compute the cost vector. `X` and `y` should be the learning sample, that is, the sample that was used to fit the tree `t`. The function partitions the sample into 10 subsamples, chosen randomly but with roughly equal size. For classification trees, the subsamples also have roughly the same class proportions. For each subsample, `test` fits a tree to the remaining data and uses it to predict the subsample. It pools the information from all subsamples to compute the cost for the whole sample.

`[cost, secost, ntnodes, bestlevel] = test(...)` also returns the vector `secost` containing the standard error of each cost value, the vector `ntnodes` containing the number of terminal nodes for each

subtree, and the scalar `bestlevel` containing the estimated best level of pruning. A `bestlevel` of 0 means no pruning. The best level is the one that produces the smallest tree that is within one standard error of the minimum-cost subtree.

[...] = `test(...,param1,val1,param2,val2,...)` specifies optional parameter name/value pairs for methods other than 'resubstitution', chosen from the following:

- 'weights' — Observation weights.
- 'nsamples' — The number of cross-validation samples (default is 10).
- 'treesize' — Either 'se' (default) to choose the smallest tree whose cost is within one standard error of the minimum cost, or 'min' to choose the minimal cost tree.

Examples

Find the best tree for Fisher's iris data using cross-validation. Start with a large tree:

```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'},...
                'splitmin',5)

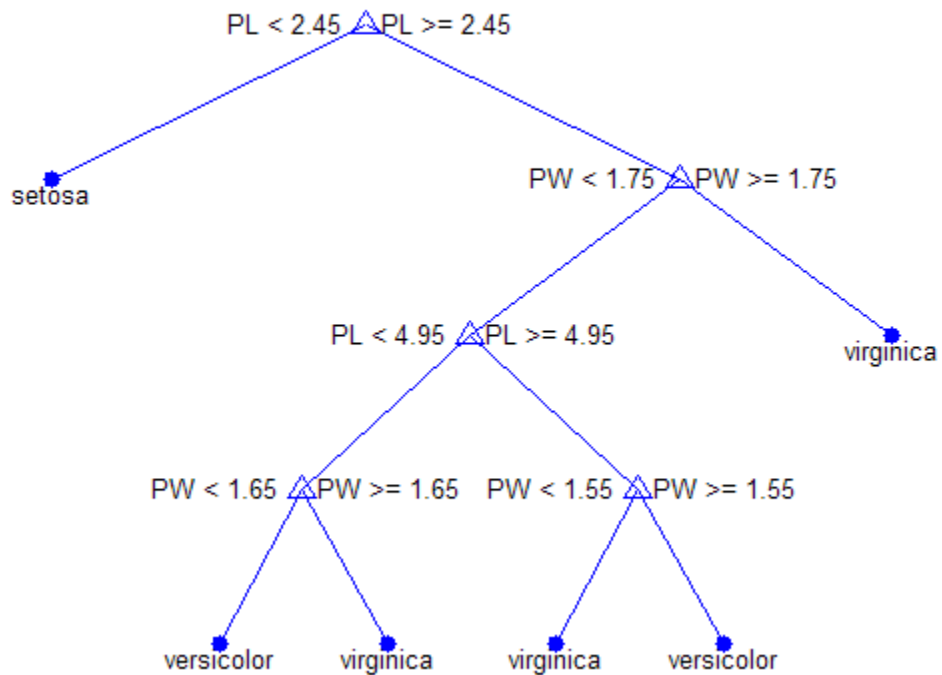
t =
Decision tree for classification
 1 if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
 2 class = setosa
 3 if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
 4 if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
 5 class = virginica
 6 if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
 7 if PW<1.55 then node 10 elseif PW>=1.55 then node 11 else virginica
 8 class = versicolor
 9 class = virginica
10 class = virginica
```

classregtree.test

```
11 class = versicolor
```

```
view(t)
```

Click to display: Magnification: Pruning level:



Find the minimum-cost tree:

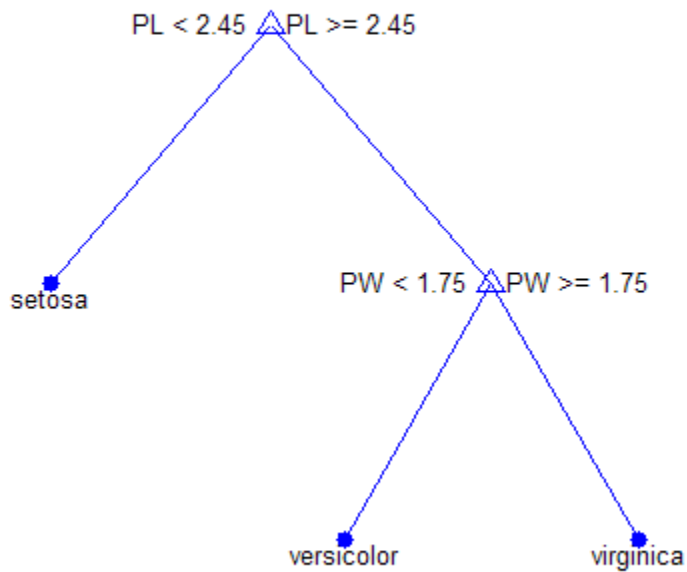
```
[c,s,n,best] = test(t,'cross',meas,species);  
tmin = prune(t,'level',best)  
tmin =  
Decision tree for classification
```



```
1 if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2 class = setosa
3 if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4 class = versicolor
5 class = virginica
```

```
view(tmin)
```

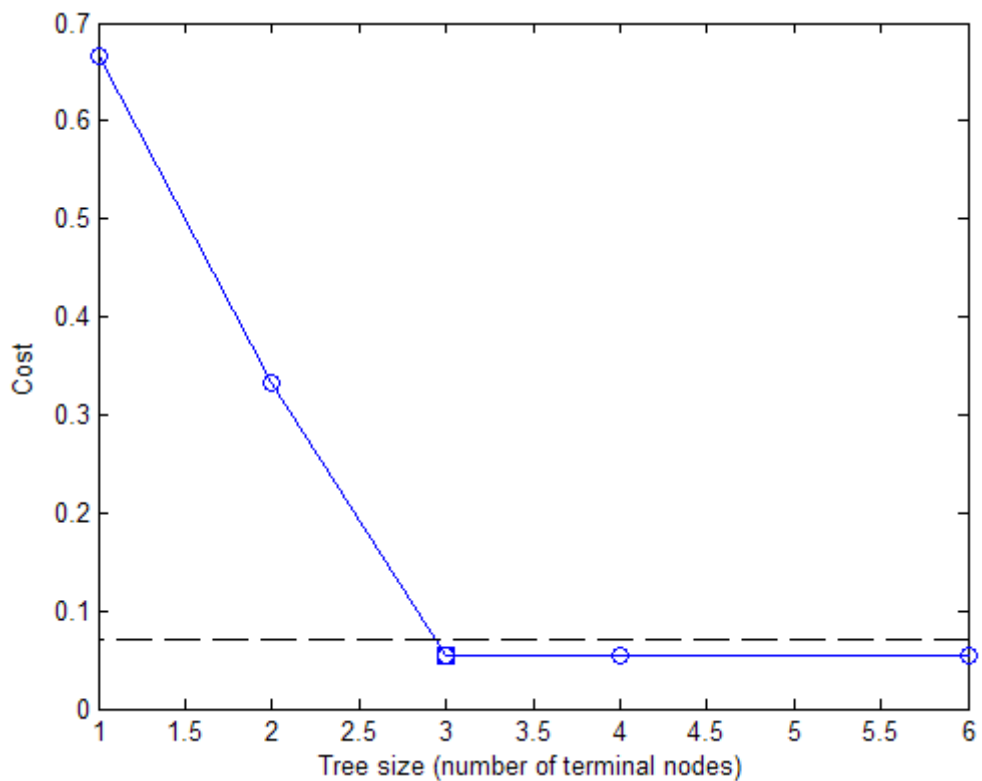
Click to display: Magnification: Pruning level:



Plot the smallest tree within one standard error of the minimum cost tree:

classregtree.test

```
[mincost,minloc] = min(c);  
plot(n,c,'b-o',...  
      n(best+1),c(best+1),'bs',...  
      n,(mincost+s(minloc))*ones(size(n)), 'k--')  
xlabel('Tree size (number of terminal nodes)')  
ylabel('Cost')
```



The solid line shows the estimated cost for each tree size, the dashed line marks one standard error above the minimum, and the square marks the smallest tree under the dashed line.

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

`classregtree` | `eval` | `view` | `prune`

cvpartition.test

Purpose Test indices for cross-validation

Syntax `idx = test(c)`
`idx = test(c,i)`

Description `idx = test(c)` returns the logical vector `idx` of test indices for an object `c` of the `cvpartition` class of type `'holdout'` or `'resubstitution'`.

If `c.Type` is `'holdout'`, `idx` specifies the observations in the test set.

If `c.Type` is `'resubstitution'`, `idx` specifies all observations.

`idx = test(c,i)` returns the logical vector `idx` of test indices for repetition `i` of an object `c` of the `cvpartition` class of type `'kfold'` or `'leaveout'`.

If `c.Type` is `'kfold'`, `idx` specifies the observations in the test set in fold `i`.

If `c.Type` is `'leaveout'`, `idx` specifies the observation left out at repetition `i`.

Examples Identify the test indices in the first fold of a partition of 10 observations for 3-fold cross-validation:

```
c = cvpartition(10,'kfold',3)
c =
K-fold cross validation partition
```

```
      N: 10
  NumTestSets: 3
   TrainSize: 7  6  7
   TestSize:  3  4  3
```

```
test(c,1)
ans =
     1
     1
     0
     0
```

0
0
0
0
1
0

See Also [cvpartition | training](#)

cvpartition.TestSize property

Purpose

Size of each test set

Description

Value is a vector in partitions of type 'kfold' and 'leaveout'.
Value is a scalar in partitions of type 'holdout' and
'resubstitution'.

Purpose Rank adjusted for ties

Syntax

```
[R,TIEADJ] = tiedrank(X)
[R,TIEADJ] = tiedrank(X,1)
[R,TIEADJ] = tiedrank(X,0,1)
```

Description [R,TIEADJ] = tiedrank(X) computes the ranks of the values in the vector X. If any X values are tied, tiedrank computes their average rank. The return value TIEADJ is an adjustment for ties required by the nonparametric tests signrank and ranksum, and for the computation of Spearman's rank correlation.

[R,TIEADJ] = tiedrank(X,1) computes the ranks of the values in the vector X. TIEADJ is a vector of three adjustments for ties required in the computation of Kendall's tau. tiedrank(X,0) is the same as tiedrank(X).

[R,TIEADJ] = tiedrank(X,0,1) computes the ranks from each end, so that the smallest and largest values get rank 1, the next smallest and largest get rank 2, etc. These ranks are used in the Ansari-Bradley test.

Examples Counting from smallest to largest, the two 20 values are 2nd and 3rd, so they both get rank 2.5 (average of 2 and 3):

```
tiedrank([10 20 30 40 20])
ans =
    1.0000    2.5000    4.0000    5.0000    2.5000
```

See Also ansaribradley | corr | partialcorr | ranksum | signrank

categorical.times

Purpose Product of categorical arrays

Syntax `C = times(A,B)`

Description `C = times(A,B)` returns a categorical array each of whose elements has the level formed from the concatenation of the levels of the corresponding elements of `A` and `B`. The set of levels of `C` is the cartesian product of the sets of levels of `A` and of `B`. The syntax `A .* B` calls `C = times(A,B)`.

See Also `categorical`

Purpose Student's *t* inverse cumulative distribution function

Syntax `X = tinv(P,V)`

Description `X = tinv(P,V)` computes the inverse of Student's *t* cdf using the degrees of freedom in *V* for the corresponding probabilities in *P*. *P* and *V* can be vectors, matrices, or multidimensional arrays that are the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The values in *P* must lie on the interval [0 1].

The *t* inverse function in terms of the *t* cdf is

$$x = F^{-1}(p | \nu) = \{x : F(x | \nu) = p\}$$

where

$$p = F(x | \nu) = \int_{-\infty}^x \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right)} \frac{1}{\sqrt{\nu\pi}} \frac{1}{\left(1 + \frac{t^2}{\nu}\right)^{\frac{\nu+1}{2}}} dt$$

The result, *x*, is the solution of the cdf integral with parameter *ν*, where you supply the desired probability *p*.

Examples What is the 99th percentile of the *t* distribution for one to six degrees of freedom?

```
percentile = tinv(0.99,1:6)
percentile =
    31.8205    6.9646    4.5407    3.7469    3.3649    3.1427
```

See Also `icdf | tcdf | tpdf | trnd | tstat`

How To • “Student’s *t* Distribution” on page B-108

Purpose Student's t probability density function

Syntax `Y = tpdf(X,V)`

Description `Y = tpdf(X,V)` computes Student's t pdf at each of the values in X using the corresponding degrees of freedom in V . X and V can be vectors, matrices, or multidimensional arrays that have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs.

Student's t pdf is

$$y = f(x | \nu) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right)} \frac{1}{\sqrt{\nu\pi}} \frac{1}{\left(1 + \frac{x^2}{\nu}\right)^{\frac{\nu+1}{2}}}$$

Examples

The mode of the t distribution is at $x = 0$. This example shows that the value of the function at the mode is an increasing function of the degrees of freedom.

```
tpdf(0,1:6)
ans =
    0.3183    0.3536    0.3676    0.3750    0.3796    0.3827
```

The t distribution converges to the standard normal distribution as the degrees of freedom approaches infinity. How good is the approximation for $\nu = 30$?

```
difference = tpdf(-2.5:2.5,30) - normpdf(-2.5:2.5)
difference =
    0.0035   -0.0006   -0.0042   -0.0042   -0.0006   0.0035
```

See Also

`pdf` | `tcdf` | `tinvs` | `tstat` | `trnd`

How To

- “Student’s t Distribution” on page B-108

cvpartition.training

Purpose Training indices for cross-validation

Syntax `idx = training(c)`
`idx = training(c,i)`

Description `idx = training(c)` returns the logical vector `idx` of training indices for an object `c` of the `cvpartition` class of type `'holdout'` or `'resubstitution'`.

If `c.Type` is `'holdout'`, `idx` specifies the observations in the training set.

If `c.Type` is `'resubstitution'`, `idx` specifies all observations.

`idx = training(c,i)` returns the logical vector `idx` of training indices for repetition `i` of an object `c` of the `cvpartition` class of type `'kfold'` or `'leaveout'`.

If `c.Type` is `'kfold'`, `idx` specifies the observations in the training set in fold `i`.

If `c.Type` is `'leaveout'`, `idx` specifies the observations left in at repetition `i`.

Examples Identify the training indices in the first fold of a partition of 10 observations for 3-fold cross-validation:

```
c = cvpartition(10,'kfold',3)
c =
K-fold cross validation partition
      N: 10
  NumTestSets: 3
   TrainSize: 7 6 7
   TestSize: 3 4 3

training(c,1)
ans =
     0
     0
```

1
1
1
1
1
1
1
0
1

See Also [cvpartition | test](#)

cvpartition.TrainSize property

Purpose Size of each training set

Description Value is a vector in partitions of type 'kfold' and 'leaveout'.
Value is a scalar in partitions of type 'holdout' and 'resubstitution'.

See Also type

Purpose Transpose categorical matrix

Syntax `B = transpose(A)`

Description `B = transpose(A)` returns the transpose of the 2-D categorical matrix `A`. `ctranspose` is identical to `transpose` for categorical arrays. The syntax `A.'` calls `transpose`.

See Also `ctranspose` | `permute`

TreeBagger.TreeArgs property

Purpose Cell array of arguments for `classregtree`

Description The `TreeArgs` property is a cell array of arguments for the `classregtree` constructor. `TreeBagger` uses these arguments in growing new trees for the ensemble.

Purpose

Bootstrap aggregation for ensemble of decision trees

Description

TreeBagger bags an ensemble of decision trees for either classification or regression. Bagging stands for bootstrap aggregation. Every tree in the ensemble is grown on an independently drawn bootstrap replica of input data. Observations not included in this replica are "out of bag" for this tree. To compute prediction of an ensemble of trees for unseen data, TreeBagger takes an average of predictions from individual trees. To estimate the prediction error of the bagged ensemble, you can compute predictions for each tree on its out-of-bag observations, average these predictions over the entire ensemble for each observation and then compare the predicted out-of-bag response with the true value at this observation.

TreeBagger relies on the `classregtree` functionality for growing individual trees. In particular, `classregtree` accepts the number of features selected at random for each decision split as an optional input argument.

The `Compact` property contains another class, `CompactTreeBagger`, with sufficient information to make predictions using new data. This information includes the tree ensemble, variable names, and class names (for classification). `CompactTreeBagger` requires less memory than `TreeBagger`, but only `TreeBagger` has methods for growing more trees for the ensemble. Once you grow an ensemble of trees using `TreeBagger` and no longer need access to the training data, you can opt to work with the compact version of the trained ensemble from then on.

Construction

TreeBagger

Create ensemble of bagged decision trees

Methods

append

Append new trees to ensemble

compact

Compact ensemble of decision trees

error	Error (misclassification probability or MSE)
fillProximities	Proximity matrix for training data
growTrees	Train additional trees and add to ensemble
margin	Classification margin
mdsProx	Multidimensional scaling of proximity matrix
meanMargin	Mean classification margin
oobError	Out-of-bag error
oobMargin	Out-of-bag margins
oobMeanMargin	Out-of-bag mean margins
oobPredict	Ensemble predictions for out-of-bag observations
predict	Predict response

Properties

ClassNames

A cell array containing the class names for the response variable Y . This property is empty for regression trees.

ComputeOOBPrediction

A logical flag specifying whether out-of-bag predictions for training observations should be computed. The default is `false`.

If this flag is true, the following properties are available:

- `OOBIndices`
- `OOBInstanceWeight`

If this flag is true, the following methods can be called:

- `oobError`
- `oobMargin`
- `oobMeanMargin`

See also `oobError`, `OOBIndices`, `OOBInstanceWeight`, `oobMargin`, `oobMeanMargin`.

ComputeOOBVarImp

A logical flag specifying whether out-of-bag estimates of variable importance should be computed. The default is `false`. If this flag is `true`, then `ComputeOOBPrediction` is `true` as well.

If this flag is `true`, the following properties are available:

- `OOBPermutedVarDeltaError`
- `OOBPermutedVarDeltaMeanMargin`
- `OOBPermutedVarCountRaiseMargin`

Cost

A matrix with misclassification costs. This property is empty for ensembles of regression trees.

See also `classregtree`.

DefaultYfit

Default value returned by `predict` and `oobPredict`. The `DefaultYfit` property controls what predicted value is returned when no prediction is possible. For example, when `oobPredict` needs to predict for an observation that is in-bag for all trees in the ensemble.

- For classification, you can set this property to either `' '` or `'MostPopular'`. If you choose `'MostPopular'` (the default), the property value becomes the name of the most probably class in

the training data. If you choose ' ', the in-bag observations are excluded from computation of the out-of-bag error and margin.

- For regression, you can set this property to any numeric scalar. The default value is the mean of the response for the training data. If you set this property to NaN, the in-bag observations are excluded from computation of the out-of-bag error and margin.

DeltaCritDecisionSplit

A numeric array of size 1-by-*Nvars* of changes in the split criterion summed over splits on each variable, averaged across the entire ensemble of grown trees.

See also `classregtree.varimportance`.

FBoot

Fraction of observations that are randomly selected with replacement for each bootstrap replica. The size of each replica is $Nobs \times FBoot$, where *Nobs* is the number of observations in the training set. The default value is 1.

MergeLeaves

A logical flag specifying whether decision tree leaves with the same parent are merged for splits that do not decrease the total risk. The default value is `false`.

Method

Method used by trees. The possible values are 'classification' for classification ensembles, and 'regression' for regression ensembles.

MinLeaf

Minimum number of observations per tree leaf. By default, `MinLeaf` is 1 for classification and 5 for regression. For `classregtree` training, the `MinParent` value is set equal to $2 \times \text{MinLeaf}$.

NTrees

Scalar value equal to the number of decision trees in the ensemble.

NVarSplit

A numeric array of size 1-by-*Nvars*, where every element gives a number of splits on this predictor summed over all trees.

NVarToSample

Number of predictor or feature variables to select at random for each decision split. By default, `NVarToSample` is equal to the square root of the total number of variables for classification, and one third of the total number of variables for regression.

OOBIndices

Logical array of size *Nobs*-by-*NTrees*, where *Nobs* is the number of observations in the training data and *NTrees* is the number of trees in the ensemble. A true value for the (i,j) element indicates that observation *i* is out-of-bag for tree *j*. In other words, observation *i* was not selected for the training data used to grow tree *j*.

OOBInstanceWeight

Numeric array of size *Nobs*-by-1 containing the number of trees used for computing the out-of-bag response for each observation. *Nobs* is the number of observations in the training data used to create the ensemble.

OOBPermutedVarCountRaiseMargin

A numeric array of size 1-by-*Nvars* containing a measure of variable importance for each predictor variable (feature). For any variable, the measure is the difference between the number of raised margins and the number of lowered margins if the values of that variable are permuted across the out-of-bag observations. This measure is computed for every tree, then averaged over the entire ensemble and divided by the standard deviation over the entire ensemble. This property is empty for regression trees.

OOBPermutedVarDeltaError

A numeric array of size 1-by-*Nvars* containing a measure of importance for each predictor variable (feature). For any variable, the measure is the increase in prediction error if the values of that variable are permuted across the out-of-bag observations. This measure is computed for every tree, then averaged over the entire ensemble and divided by the standard deviation over the entire ensemble.

OOBPermutedVarDeltaMeanMargin

A numeric array of size 1-by-*Nvars* containing a measure of importance for each predictor variable (feature). For any variable, the measure is the decrease in the classification margin if the values of that variable are permuted across the out-of-bag observations. This measure is computed for every tree, then averaged over the entire ensemble and divided by the standard deviation over the entire ensemble. This property is empty for regression trees.

OutlierMeasure

A numeric array of size *Nobs*-by-1, where *Nobs* is the number of observations in the training data, containing outlier measures for each observation.

See also `CompactTreeBagger.OutlierMeasure`.

Prior

A vector with prior probabilities for classes. This property is empty for ensembles of regression trees.

See also `classregtree`.

Proximity

A numeric matrix of size *Nobs*-by-*Nobs*, where *Nobs* is the number of observations in the training data, containing measures of the proximity between observations. For any two observations, their proximity is defined as the fraction of trees for which these observations land on the same leaf. This is a symmetric matrix

with 1s on the diagonal and off-diagonal elements ranging from 0 to 1.

See also `CompactTreeBagger.proximity`, `classregtree.varimportance`.

Prune

The `Prune` property is true if decision trees are pruned and false if they are not. Pruning decision trees is not recommended for ensembles. The default value is false.

See also `classregtree.prune`.

SampleWithReplacement

A logical flag specifying if data are sampled for each decision tree with replacement. True if `TreeBagger` samples data with replacement and false otherwise. True by default.

TreeArgs

Cell array of arguments for the `classregtree` constructor. These arguments are used by `TreeBagger` when growing new trees for the ensemble.

Trees

A cell array of size *NTrees*-by-1 containing the trees in the ensemble.

See also `NTrees`.

VarAssoc

A matrix of size *Nvars*-by-*Nvars* with predictive measures of variable association, averaged across the entire ensemble of grown trees. If you grew the ensemble setting `'surrogate'` to `'on'`, this matrix for each tree is filled with predictive measures of association averaged over the surrogate splits. If you grew the ensemble setting `'surrogate'` to `'off'` (default), `VarAssoc` is diagonal.

VarNames

A cell array containing the names of the predictor variables (features). `TreeBagger` takes these names from the optional 'names' parameter. The default names are 'x1', 'x2', etc.

W

Numeric vector of weights of length *Nobs*, where *Nobs* is the number of observations (rows) in the training data. `TreeBagger` uses these weights for growing every decision tree in the ensemble. The default *W* is ones(*Nobs*, 1).

X

A numeric matrix of size *Nobs*-by-*Nvars*, where *Nobs* is the number of observations (rows) and *Nvars* is the number of variables (columns) in the training data. This matrix contains the predictor (or feature) values.

Y

An array of true class labels for classification, or response values for regression. *Y* can be a numeric column vector, a character matrix, or a cell array of strings.

Copy Semantics

Value. To learn how this affects your use of the class, see [Comparing Handle and Value Classes in the MATLAB Object-Oriented Programming documentation](#).

How To

- “Ensemble Methods” on page 13-54
- “Classification Trees and Regression Trees” on page 13-30
- “Grouping Variables” on page 2-72

Purpose

Create ensemble of bagged decision trees

Syntax

```
B = TreeBagger(ntrees,X,Y)
B = TreeBagger(ntrees,X,Y,'param1',val1,'param2',val2,...)
```

Description

`B = TreeBagger(ntrees,X,Y)` creates an ensemble `B` of `ntrees` decision trees for predicting response `Y` as a function of predictors `X`. By default `TreeBagger` builds an ensemble of classification trees. The function can build an ensemble of regression trees by setting the optional input argument `'method'` to `'regression'`.

`X` is a numeric matrix of training data. Each row represents an observation and each column represents a predictor or feature. `Y` is an array of true class labels for classification or numeric function values for regression. True class labels can be a numeric vector, character matrix, vector cell array of strings or categorical vector. `TreeBagger` converts labels to a cell array of strings for classification.

For more information on grouping variables, see “Grouping Variables” on page 2-72.

`B = TreeBagger(ntrees,X,Y,'param1',val1,'param2',val2,...)` specifies optional parameter name/value pairs:

<code>'FBoot'</code>	Fraction of input data to sample with replacement from the input data for growing each new tree. Default value is 1.
<code>'OOBPred'</code>	<code>'on'</code> to store info on what observations are out of bag for each tree. This info can be used by <code>oobPredict</code> to compute the predicted class probabilities for each tree in the ensemble. Default is <code>'off'</code> .
<code>'OOBVarImp'</code>	<code>'on'</code> to store out-of-bag estimates of feature importance in the ensemble. Default is <code>'off'</code> . Specifying <code>'on'</code> also sets the <code>'OOBPred'</code> value to <code>'on'</code> .

TreeBagger

'Method'	Either 'classification' or 'regression'. Regression requires a numeric Y.
'NVarToSample'	Number of variables to select at random for each decision split. Default is the square root of the number of variables for classification and one third of the number of variables for regression. Valid values are 'all' or a positive integer. Setting this argument to any valid value but 'all' invokes Breiman's 'random forest' algorithm.
'NPrint'	Number of training cycles (grown trees) after which TreeBagger displays a diagnostic message showing training progress. Default is no diagnostic messages.
'MinLeaf'	Minimum number of observations per tree leaf. Default is 1 for classification and 5 for regression.
'Options'	<p>A structure that specifies options that govern the computation when growing the ensemble of decision trees. One option requests that the computation of decision trees on multiple bootstrap replicates uses multiple processors, if the Parallel Computing Toolbox is available. Two options specify the random number streams to use in selecting bootstrap replicates. You can create this argument with a call to <code>statset</code>. You can retrieve values of the individual fields with a call to <code>statget</code>. Applicable <code>statset</code> parameters are:</p> <ul style="list-style-type: none">• 'UseParallel' — If 'always' and if a <code>matlabpool</code> of the Parallel Computing Toolbox is open, compute decision trees drawn on separate bootstrap replicates in parallel. If the Parallel Computing Toolbox is not installed, or a <code>matlabpool</code> is not open, computation occurs in serial mode. Default is 'never', or serial computation.

- 'UseSubstreams' — If 'always' select each bootstrap replicate using a separate Substream of the random number generator (aka Stream). This option is available only with RandStream types that support Substreams: 'mlfg6331_64' or 'mrg32k3a'. Default is 'never', do not use a different Substream to compute each bootstrap replicate.
- Streams — A RandStream object or cell array of such objects. If you do not specify Streams, TreeBagger uses the default stream or streams. If you choose to specify Streams, use a single object except in the case
 - You have an open MATLAB pool
 - UseParallel is 'always'
 - UseSubstreams is 'never'In that case, use a cell array the same size as the MATLAB pool.

In addition to the optional arguments above, this method accepts all optional `classregtree` arguments with the exception of 'minparent'. Refer to the documentation for `classregtree` for more detail.

Examples

```
load fisheriris
b = TreeBagger(50,meas,species,'OOBPred','on')
plot(oobError(b))
xlabel('number of grown trees')
ylabel('out-of-bag classification error')
```

returns

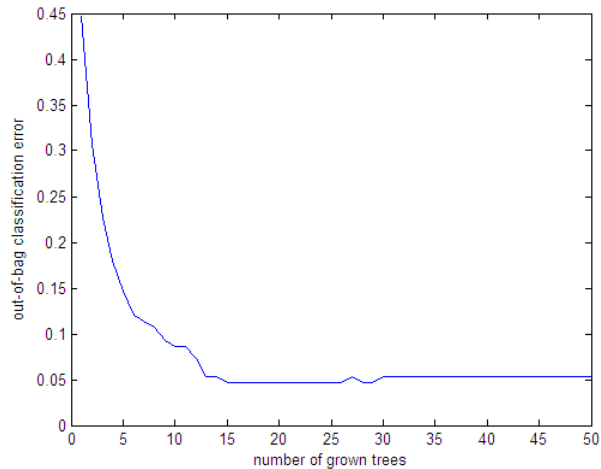
b =

Ensemble with 50 bagged decision trees:

Training X: [150x4]

TreeBagger

```
Training Y: [150x1]
Method: classification
Nvars: 4
NVarToSample: 2
MinLeaf: 1
FBoot: 1
SampleWithReplacement: 1
ComputeOOBPrediction: 1
ComputeOOBVarImp: 0
Proximity: []
Prune: 0
MergeLeaves: 0
TreeArgs:
ClassNames: 'setosa' 'versicolor' 'virginica'
```



See Also

`classregtree` | `CompactTreeBagger`

How To

- “Ensemble Methods” on page 13-54
- “Grouping Variables” on page 2-72

Purpose Plot tree

Note treedisp will be removed in a future release. Use `classregtree.view` instead.

Syntax

```
treedisp(t)
treedisp(t,param1,va11,param2,va12,...)
```

Description

Note This function is superseded by the `view` method of the `classregtree` class and is maintained only for backwards compatibility. It accepts objects `t` created with the `classregtree` constructor.

`treedisp(t)` takes as input a decision tree `t` as computed by the `treefit` function, and displays it in a figure window. Each branch in the tree is labeled with its decision rule, and each terminal node is labeled with the predicted value for that node.

For each branch node, the left child node corresponds to the points that satisfy the condition, and the right child node corresponds to the points that do not satisfy the condition.

The **Click to display** pop-up menu at the top of the figure enables you to display more information about each node, as described in the following table.

Menu Choice	Displays
Identity	The node number, whether the node is a branch or a leaf, and the rule that governs the node
Variable ranges	The range of each of the predictor variables for that node
Node statistics	Descriptive statistics for the observations falling into this node

treedisp

After you select the type of information you want, click any node to display the information for that node.

The **Pruning level** button displays the number of levels that have been cut from the tree and the number of levels in the unpruned tree. For example, 1 of 6 indicates that the unpruned tree has six levels, and that one level has been cut from the tree. Use the spin button to change the pruning level.

`treedisp(t,param1,val1,param2,val2,...)` specifies optional parameter name-value pairs, listed in the following table.

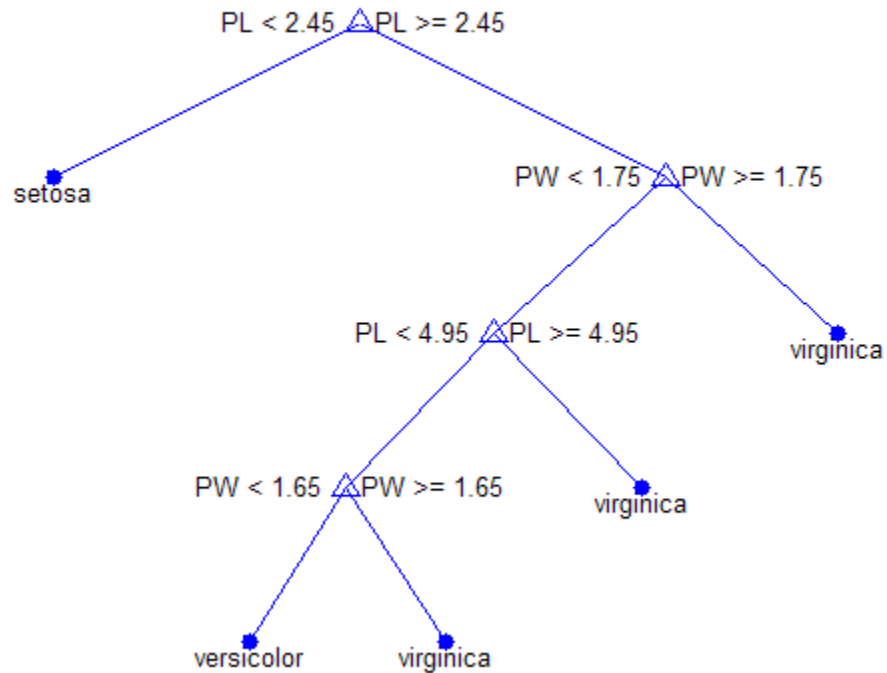
Parameter	Value
'names'	A cell array of names for the predictor variables, in the order in which they appear in the X matrix from which the tree was created (see <code>treefit</code>)
'prunelevel'	Initial pruning level to display

Examples

Create and graph classification tree for Fisher's iris data. The names in this example are abbreviations for the column contents (sepal length, sepal width, petal length, and petal width).

```
load fisheriris;
t = treefit(meas,species);
treedisp(t,'names',{'SL' 'SW' 'PL' 'PW'});
```

Click to display: Magnification: Pruning level:



References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

[treefit](#) | [treeprune](#) | [treetest](#)

treefit

Purpose Fit tree

Note treefit will be removed in a future release. Use classregtree instead.

Syntax

```
t = treefit(X,y)
t = treefit(X,y,param1,val1,param2,val2,...)
```

Description

Note This function is superseded by the classregtree constructor of the classregtree class and is maintained only for backwards compatibility. It returns objects *t* in the classregtree class.

t = treefit(*X*,*y*) creates a decision tree *t* for predicting response *y* as a function of predictors *X*. *X* is an *n*-by-*m* matrix of predictor values. *y* is either a vector of *n* response values (for regression), or a character array or cell array of strings containing *n* class names (for classification). Either way, *t* is a binary tree where each non-terminal node is split based on the values of a column of *X*.

t = treefit(*X*,*y*,*param1*,*val1*,*param2*,*val2*,...) specifies optional parameter name-value pairs. Valid parameter strings are:

The following table lists parameters available for all trees.

Parameter	Value
'catidx'	Vector of indices of the columns of <i>X</i> . treefit treats these columns as unordered categorical values.
'method'	Either 'classification' (default if <i>y</i> is text) or 'regression' (default if <i>y</i> is numeric).

Parameter	Value
'splitmin'	A number n such that impure nodes must have n or more observations to be split (default 10).
'prune'	'on' (default) to compute the full tree and a sequence of pruned subtrees, or 'off' for the full tree without pruning.

The following table lists parameters available for classification trees only.

Parameter	Value
'cost'	p -by- p matrix C , where p is the number of distinct response values or class names in the input y . $C(i, j)$ is the cost of classifying a point into class j if its true class is i . (The default has $C(i, j)=1$ if $i \neq j$, and $C(i, j)=0$ if $i=j$.) C can also be a structure S with two fields: $S.group$ containing the group names, and $S.cost$ containing a matrix of cost values.
'splitcriterion'	Criterion for choosing a split: either 'gdi' (default) for Gini's diversity index, 'twoing' for the twoing rule, or 'deviance' for maximum deviance reduction.
'priorprob'	Prior probabilities for each class, specified as a vector (one value for each distinct group name) or as a structure S with two fields: $S.group$ containing the group names, and $S.prob$ containing a vector of corresponding probabilities.

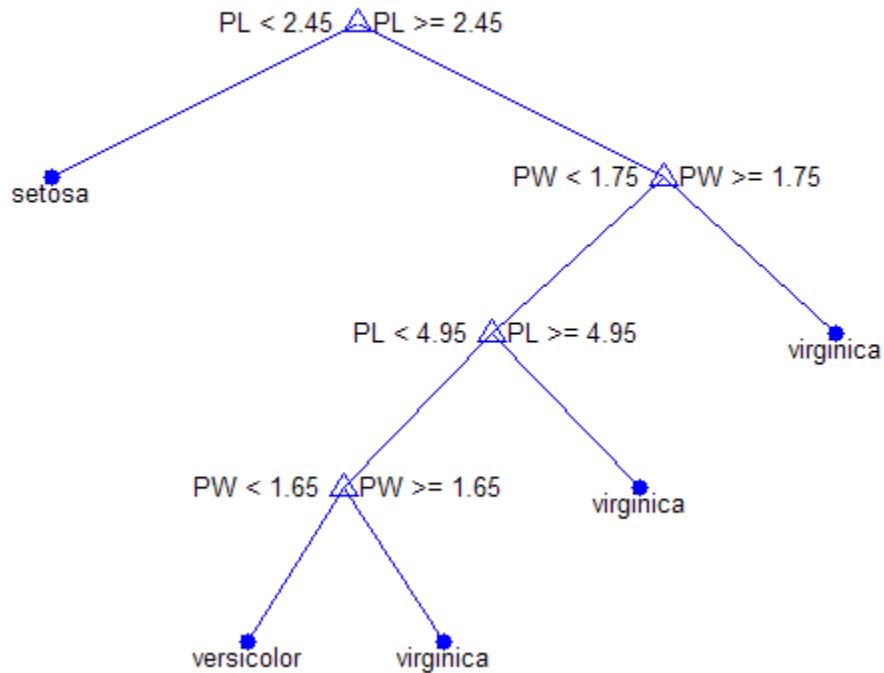
Examples

Create a classification tree for Fisher's iris data:

```
load fisheriris;
t = treefit(meas,species);
treedisp(t,'names',{'SL' 'SW' 'PL' 'PW'});
```

treefit

Click to display: Magnification: Pruning level:



References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

treedisp | treetest

How To

- “Grouping Variables” on page 2-72

Purpose

Prune tree

Note treeprune will be removed in a future release. Use `classregtree.prune` instead.

Syntax

```
t2 = treeprune(t1,'level',level)
t2 = treeprune(t1,'nodes',nodes)
t2 = treeprune(t1)
```

Description

Note This function is superseded by the `prune` method of the `classregtree` class and is maintained only for backwards compatibility. It accepts objects `t1` created with the `classregtree` constructor and returns objects `t2` in the `classregtree` class.

`t2 = treeprune(t1,'level',level)` takes a decision tree `t1` as created by the `treefit` function, and a pruning level, and returns the decision tree `t2` pruned to that level. Setting `level` to 0 means no pruning. Trees are pruned based on an optimal pruning scheme that first prunes branches giving less improvement in error cost.

`t2 = treeprune(t1,'nodes',nodes)` prunes the nodes listed in the `nodes` vector from the tree. Any `t1` branch nodes listed in `nodes` become leaf nodes in `t2`, unless their parent nodes are also pruned. The `treedisp` function can display the node numbers for any node you select.

`t2 = treeprune(t1)` returns the decision tree `t2` that is the same as `t1`, but with the optimal pruning information added. This is useful only if you created `t1` by pruning another tree, or by using the `treefit` function with pruning set 'off'. If you plan to prune a tree multiple times, it is more efficient to create the optimal pruning sequence first.

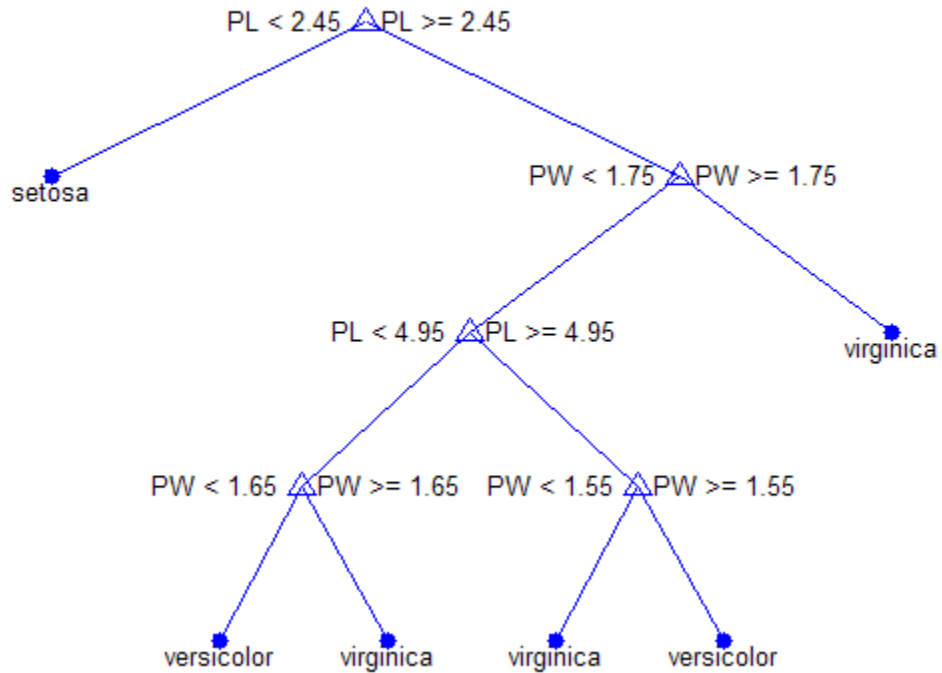
Pruning is the process of reducing a tree by turning some branch nodes into leaf nodes, and removing the leaf nodes under the original branch.

treeprune

Examples

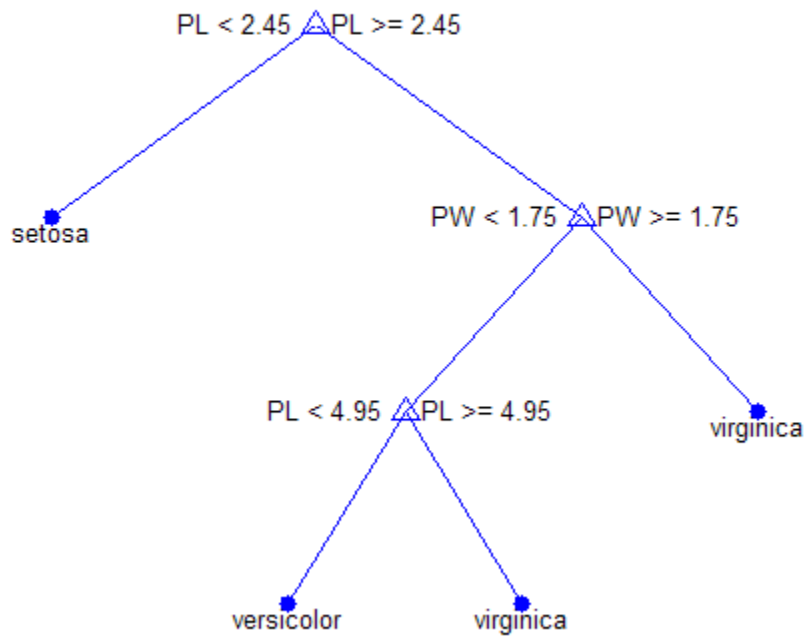
Display the full tree for Fisher's iris data, as well as the next largest tree from the optimal pruning sequence:

```
load fisheriris;  
t1 = treefit(meas,species,'splitmin',5);  
treedisp(t1,'names',{'SL' 'SW' 'PL' 'PW'});
```



```
t2 = treeprune(t1,'level',1);  
treedisp(t2,'names',{'SL' 'SW' 'PL' 'PW'});
```

Click to display: Magnification: Pruning level:



References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

[treefit](#) | [treetest](#) | [treedisp](#)

TreeBagger.Trees property

Purpose Decision trees in ensemble

Description The Trees property is a cell array of size NTrees-by-1 containing the trees in the ensemble.

See Also NTrees

Purpose

Error rate

Syntax

```
cost = treetest(t,'resubstitution')
cost = treetest(t,'test',X,y)
cost = treetest(t,'crossvalidate',X,y)
[cost,secost,ntnodes,bestlevel] = treetest(...)
[...] = treetest(...,param1,val1,param2,val2,...)
```

Note `treetest` will be removed in a future release. Use `classregtree.test` instead.

Description

Note This function is superseded by the `test` method of the `classregtree` class and is maintained only for backwards compatibility. It accepts objects `t` created with the `classregtree` constructor.

`cost = treetest(t,'resubstitution')` computes the cost of the tree `t` using a resubstitution method. `t` is a decision tree as created by the `treefit` function. The cost of the tree is the sum over all terminal nodes of the estimated probability of that node times the node's cost. If `t` is a classification tree, the cost of a node is the sum of the misclassification costs of the observations in that node. If `t` is a regression tree, the cost of a node is the average squared error over the observations in that node. `cost` is a vector of cost values for each subtree in the optimal pruning sequence for `t`. The resubstitution cost is based on the same sample that was used to create the original tree, so it underestimates the likely cost of applying the tree to new data.

`cost = treetest(t,'test',X,y)` uses the predictor matrix `X` and response `y` as a test sample, applies the decision tree `t` to that sample, and returns a vector `cost` of cost values computed for the test sample. `X` and `y` should not be the same as the learning sample, which is the sample that was used to fit the tree `t`.

`cost = treetest(t, 'crossvalidate', X, y)` uses 10-fold cross-validation to compute the cost vector. `X` and `y` should be the learning sample, which is the sample that was used to fit the tree `t`. The function partitions the sample into 10 subsamples, chosen randomly but with roughly equal size. For classification trees, the subsamples also have roughly the same class proportions. For each subsample, `treetest` fits a tree to the remaining data and uses it to predict the subsample. It pools the information from all subsamples to compute the cost for the whole sample.

`[cost, secost, ntnodes, bestlevel] = treetest(...)` also returns the vector `secost` containing the standard error of each cost value, the vector `ntnodes` containing number of terminal nodes for each subtree, and the scalar `bestlevel` containing the estimated best level of pruning. `bestlevel = 0` means no pruning, i.e., the full unpruned tree. The best level is the one that produces the smallest tree that is within one standard error of the minimum-cost subtree.

`[...] = treetest(..., param1, val1, param2, val2, ...)` specifies optional parameter name-value pairs chosen from the following table.

Parameter	Value
'nsamples'	The number of cross-validations samples (default is 10)
'treesize'	Either 'se' (default) to choose the smallest tree whose cost is within one standard error of the minimum cost, or 'min' to choose the minimal cost tree.

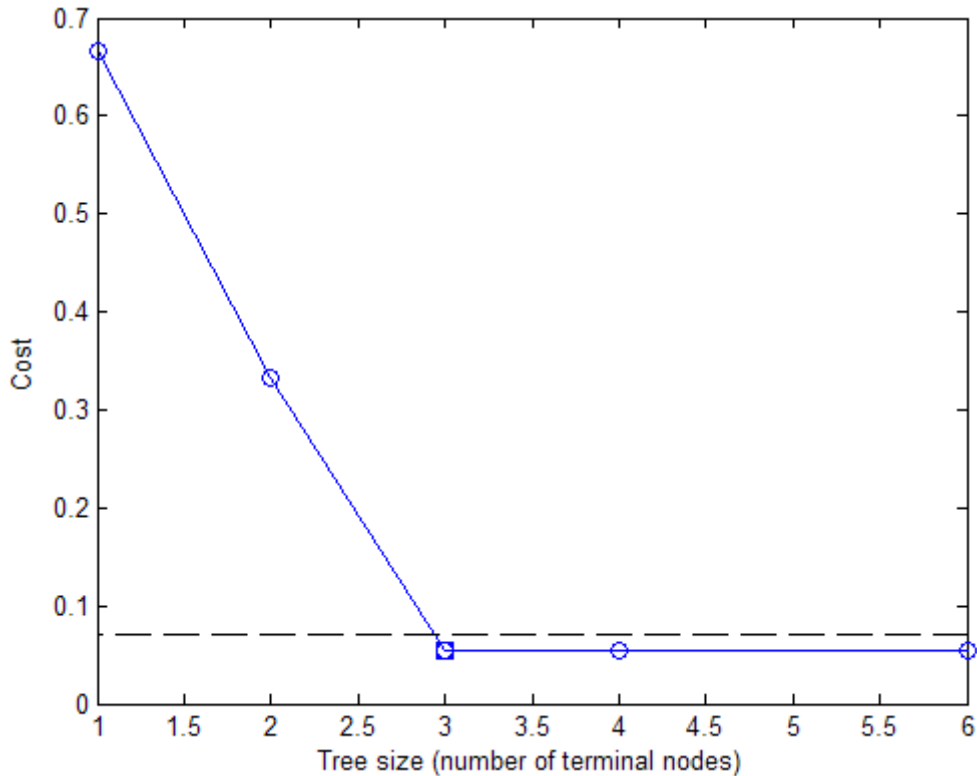
Examples

Find the best tree for Fisher's iris data using cross-validation. The solid line shows the estimated cost for each tree size, the dashed line marks one standard error above the minimum, and the square marks the smallest tree under the dashed line.

```
% Start with a large tree.  
load fisheriris;  
t = treefit(meas, species', 'splitmin', 5);
```



```
% Find the minimum-cost tree.  
[c,s,n,best] = treetest(t,'cross',meas,species);  
tmin = treeprune(t,'level',best);  
  
% Plot smallest tree within 1 std of minimum cost tree.  
[mincost,minloc] = min(c);  
plot(n,c,'b-o',...  
      n(best+1),c(best+1),'bs',...  
      n,(mincost+s(minloc))*ones(size(n)),'k--');  
xlabel('Tree size (number of terminal nodes)')  
ylabel('Cost')
```



treetest

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

treefit | treedisp

Purpose Predicted responses

Note treeval will be removed in a future release. Use `classregtree.eval` instead.

Syntax

```
yfit = treeval(t,X)
yfit = treeval(t,X,subtrees)
[yfit,node] = treeval(...)
[yfit,node,cname] = treeval(...)
```

Description

Note This function is superseded by the `eval` method of the `classregtree` class and is maintained only for backwards compatibility. It accepts objects `t` created with the `classregtree` constructor.

`yfit = treeval(t,X)` takes a classification or regression tree `t` as produced by the `treefit` function and a matrix `X` of predictor values, and produces a vector `yfit` of predicted response values. For a regression tree, `yfit(i)` is the fitted response value for a point having the predictor values `X(i,:)`. For a classification tree, `yfit(i)` is the class number into which the tree would assign the point with data `X(i,:)`. To convert the number into a class name, use the third output argument, `cname` (described below).

`yfit = treeval(t,X,subtrees)` takes an additional vector `subtrees` of pruning levels, with 0 representing the full, unpruned tree. `T` must include a pruning sequence as created by the `treefit` or `prunetree` function. If `subtree` has k elements and `X` has n rows, the output `yfit` is an n -by- k matrix, with the j th column containing the fitted values produced by the `subtrees(j)` subtree. `subtrees` must be sorted in ascending order.

`[yfit,node] = treeval(...)` also returns an array `node` of the same size as `yfit` containing the node number assigned to each row of `X`. The `treedisp` function can display the node numbers for any node you select.

treeval

[yfit,node,cname] = treeval(...) is valid only for classification trees. It returns a cell array cname containing the predicted class names.

Examples

Find the predicted classifications for Fisher's iris data:

```
load fisheriris;
t = treefit(meas,species); % Create decision tree
sfit = treeval(t,meas); % Find assigned class numbers
sfit = t.classname(sfit); % Get class names
mean(strcmp(sfit,species)) % Proportion in correct class
ans =
    0.9800
```

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

treefit | treeprune | treetest

Purpose Mean excluding outliers

Syntax

```
m = trimmean(X,percent)
trimmean(X,percent,dim)
m = trimmean(X,percent,flag)
m = trimmean(x,percent,flag,dim)
```

Description `m = trimmean(X,percent)` calculates the trimmed mean of the values in `X`. For a vector input, `m` is the mean of `X`, excluding the highest and lowest `k` data values, where $k = n * (\text{percent} / 100) / 2$ and where `n` is the number of values in `X`. For a matrix input, `m` is a row vector containing the trimmed mean of each column of `X`. For `n`-D arrays, `trimmean` operates along the first non-singleton dimension. `percent` is a scalar between 0 and 100.

`trimmean(X,percent,dim)` takes the trimmed mean along dimension `dim` of `X`.

`m = trimmean(X,percent,flag)` controls how to trim when `k` is not an integer. `flag` can be chosen from the following:

'round'	Round <code>k</code> to the nearest integer (round to a smaller integer if <code>k</code> is a half integer). This is the default.
'floor'	Round <code>k</code> down to the next smaller integer.
'weight'	If $k = i + f$ where <code>i</code> is the integer part and <code>f</code> is the fraction, compute a weighted mean with weight $(1 - f)$ for the $(i + 1)$ th and $(n - i)$ th values, and full weight for the values between them.

`m = trimmean(x,percent,flag,dim)` takes the trimmed mean along dimension `dim` of `x`.

Tips The trimmed mean is a robust estimate of the location of a sample. If there are outliers in the data, the trimmed mean is a more representative estimate of the center of the body of the data than the mean. However, if the data is all from the same probability distribution,

trimmean

then the trimmed mean is less efficient than the sample mean as an estimator of the location of the data.

Examples

Example 1

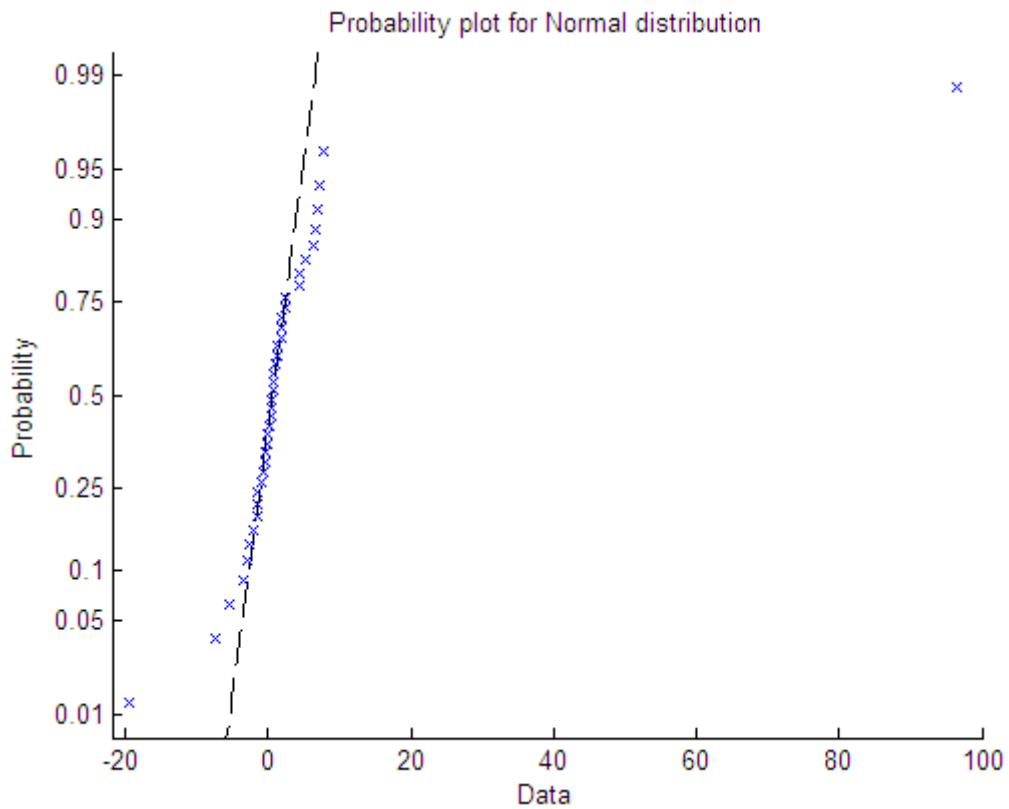
This example shows a Monte Carlo simulation of the efficiency of the 10% trimmed mean relative to the sample mean for normal data.

```
x = normrnd(0,1,100,100);
m = mean(x);
trim = trimmean(x,10);
sm = std(m);
strim = std(trim);
efficiency = (sm/strim).^2
efficiency =
    0.9702
```

Example 2

Generate random data from the t distribution, which tends to have outliers:

```
rng('default') % to reproduce the plot exactly
x = trnd(1,40,1);
probplot(x)
```



Though the distribution is symmetric around zero, there are several outliers which will affect the mean. The trimmed mean is much closer to zero, which is much more representative of the data:

```
mean(x)
```

```
ans =  
2.7991
```

```
trimmean(x,25)
```

```
ans =
```

trimmean

0.8797

See Also

mean | median | geomean | harmmean

Purpose

Student's *t* random numbers

Syntax

```
R = trnd(V)
R = trnd(V,m,n,...)
R = trnd(V,[m,n,...])
```

Description

`R = trnd(V)` generates random numbers from Student's *t* distribution with *V* degrees of freedom. *V* can be a vector, a matrix, or a multidimensional array. The size of *R* is the size of *V*.

`R = trnd(V,m,n,...)` or `R = trnd(V,[m,n,...])` generates an *m*-by-*n*-by-... array. The *V* parameter can be a scalar or an array of the same size as *R*.

Examples

```
noisy = trnd(ones(1,6))
noisy =
    19.7250    0.3488    0.2843    0.4034    0.4816   -2.4190

numbers = trnd(1:6,[1 6])
numbers =
   -1.9500   -0.9611   -0.9038    0.0754    0.9820    1.0115

numbers = trnd(3,2,6)
numbers =
   -0.3177   -0.0812   -0.6627    0.1905   -1.5585   -0.0433
    0.2536    0.5502    0.8646    0.8060   -0.5216    0.0891
```

See Also

[random](#) | [tpdf](#) | [tcdf](#) | [tinv](#) | [tstat](#)

How To

- “Student’s *t* Distribution” on page B-108

tstat

Purpose Student's t mean and variance

Syntax `[M,V] = tstat(NU)`

Description `[M,V] = tstat(NU)` returns the mean of and variance for Student's t distribution using the degrees of freedom in `NU`. `M` and `V` are the same size as `NU`.

The mean of the Student's t distribution with parameter ν is zero for values of ν greater than 1. If ν is one, the mean does not exist. The variance for values of ν greater than 2 is $\nu/(\nu-2)$.

Examples Find the mean of and variance for 1 to 30 degrees of freedom.

```
[m,v] = tstat(reshape(1:30,6,5))
```

```
m =
```

```
NaN  0  0  0  0
  0  0  0  0  0
  0  0  0  0  0
  0  0  0  0  0
  0  0  0  0  0
  0  0  0  0  0
```

```
v =
```

```
NaN  1.4000  1.1818  1.1176  1.0870
NaN  1.3333  1.1667  1.1111  1.0833
3.0000  1.2857  1.1538  1.1053  1.0800
2.0000  1.2500  1.1429  1.1000  1.0769
1.6667  1.2222  1.1333  1.0952  1.0741
1.5000  1.2000  1.1250  1.0909  1.0714
```

Note that the variance does not exist for one and two degrees of freedom.

See Also `tpdf` | `tcdf` | `tinvs` | `trnd`

Purpose

One-sample and paired-sample t -test

Syntax

```
h = ttest(x)
h = ttest(x,m)
h = ttest(x,y)
h = ttest(...,alpha)
h = ttest(...,alpha,tail)
h = ttest(...,alpha,tail,dim)
[h,p] = ttest(...)
[h,p,ci] = ttest(...)
[h,p,ci,stats] = ttest(...)
```

Description

`h = ttest(x)` performs a t -test of the null hypothesis that data in the vector `x` are a random sample from a normal distribution with mean 0 and unknown variance, against the alternative that the mean is not 0. The result of the test is returned in `h`. `h = 1` indicates a rejection of the null hypothesis at the 5% significance level. `h = 0` indicates a failure to reject the null hypothesis at the 5% significance level.

`x` can also be a matrix or an N -dimensional array. For matrices, `ttest` performs separate t -tests along each column of `x` and returns a vector of results. For N -dimensional arrays, `ttest` works along the first non-singleton dimension of `x`.

The test treats NaN values as missing data, and ignores them.

`h = ttest(x,m)` performs a t -test of the null hypothesis that data in the vector `x` are a random sample from a normal distribution with mean `m` and unknown variance, against the alternative that the mean is not `m`.

`h = ttest(x,y)` performs a paired t -test of the null hypothesis that data in the difference `x-y` are a random sample from a normal distribution with mean 0 and unknown variance, against the alternative that the mean is not 0. `x` and `y` must be vectors of the same length, or arrays of the same size.

`h = ttest(...,alpha)` performs the test at the $(100*\alpha)\%$ significance level. The default, when unspecified, is `alpha = 0.05`.

ttest

`h = ttest(...,alpha,tail)` performs the test against the alternative specified by the string `tail`. There are three options for `tail`:

- 'both' — Mean is not 0 (or `m`) (two-tailed test). This is the default, when `tail` is unspecified.
- 'right' — Mean is greater than 0 (or `m`) (right-tail test)
- 'left' — Mean is less than 0 (or `m`) (left-tail test)

`tail` must be a single string, even when `x` is a matrix or an N -dimensional array.

`h = ttest(...,alpha,tail,dim)` works along dimension `dim` of `x`, or of `x-y` for a paired test. Use `[]` to pass in default values for `m`, `alpha`, or `tail`.

`[h,p] = ttest(...)` returns the p value of the test. The p value is the probability, under the null hypothesis, of observing a value as extreme or more extreme of the test statistic

$$t = \frac{\bar{x} - \mu}{s / \sqrt{n}}$$

where \bar{x} is the sample mean, $\mu = 0$ (or `m`) is the hypothesized population mean, s is the sample standard deviation, and n is the sample size. Under the null hypothesis, the test statistic will have Student's t distribution with $n - 1$ degrees of freedom.

`[h,p,ci] = ttest(...)` returns a $100*(1 - \text{alpha})\%$ confidence interval on the population mean, or on the difference of population means for a paired test.

`[h,p,ci,stats] = ttest(...)` returns the structure `stats` with the following fields:

- `tstat` — Value of the test statistic
- `df` — Degrees of freedom of the test
- `sd` — Sample standard deviation

Examples

Simulate a random sample of size 100 from a normal distribution with mean 0.1:

```
x = normrnd(0.1,1,1,100);
```

Test the null hypothesis that the sample comes from a normal distribution with mean 0:

```
[h,p,ci] = ttest(x,0)
h =
     0
p =
    0.8323
ci =
   -0.1650    0.2045
```

The test fails to reject the null hypothesis at the default $\alpha = 0.05$ significance level. Under the null hypothesis, the probability of observing a value as extreme or more extreme of the test statistic, as indicated by the p value, is much greater than α . The 95% confidence interval on the mean contains 0.

Simulate a larger random sample of size 1000 from the same distribution:

```
y = normrnd(0.1,1,1,1000);
```

Test again if the sample comes from a normal distribution with mean 0:

```
[h,p,ci] = ttest(y,0)
h =
     1
p =
    0.0160
ci =
    0.0142    0.1379
```

ttest

This time the test rejects the null hypothesis at the default $\alpha = 0.05$ significance level. The p value has fallen below $\alpha = 0.05$ and the 95% confidence interval on the mean does not contain 0.

Because the p value of the sample y is greater than 0.01, the test will fail to reject the null hypothesis when the significance level is lowered to $\alpha = 0.01$:

```
[h,p,ci] = ttest(y,0,0.01)
h =
     0
p =
    0.0160
ci =
   -0.0053    0.1574
```

Notice that at the lowered significance level the 99% confidence interval on the mean widens to contain 0.

This example will produce slightly different results each time it is run, because of the random sampling.

See Also

[ttest2](#) | [ztest](#)

Purpose

Two-sample *t*-test

Syntax

```
h = ttest2(x,y)
h = ttest2(x,y,alpha)
h = ttest2(x,y,alpha,tail)
h = ttest2(x,y,alpha,tail,vartype)
h = ttest2(x,y,alpha,tail,vartype,dim)
[h,p] = ttest2(...)
[h,p,ci] = ttest2(...)
[h,p,ci,stats] = ttest2(...)
```

Description

`h = ttest2(x,y)` performs a *t*-test of the null hypothesis that data in the vectors `x` and `y` are independent random samples from normal distributions with equal means and equal but unknown variances, against the alternative that the means are not equal. The result of the test is returned in `h`. `h = 1` indicates a rejection of the null hypothesis at the 5% significance level. `h = 0` indicates a failure to reject the null hypothesis at the 5% significance level. `x` and `y` need not be vectors of the same length.

`x` and `y` can also be matrices or *N*-dimensional arrays. Matrices `x` and `y` must have the same number of columns, in which case `ttest2` performs separate *t*-tests along each column and returns a vector of results. *N*-dimensional arrays `x` and `y` must have the same size along all but the first non-singleton dimension, in which case `ttest2` works along the first non-singleton dimension.

The test treats NaN values as missing data, and ignores them.

`h = ttest2(x,y,alpha)` performs the test at the $(100*\alpha)\%$ significance level. The default, when unspecified, is `alpha = 0.05`.

`h = ttest2(x,y,alpha,tail)` performs the test against the alternative specified by the string `tail`. There are three options for `tail`:

- 'both' — Means are not equal (two-tailed test). This is the default, when `tail` is unspecified.
- 'right' — Mean of `x` is greater than mean of `y` (right-tail test)

- 'left' — Mean of x is less than mean of y (left-tail test)

`tail` must be a single string, even when x is a matrix or an N -dimensional array.

`h = ttest2(x,y,alpha,tail,vartype)` performs the test under the assumption of equal or unequal population variances, as specified by the string `vartype`. There are two options for `vartype`:

- 'equal' — Assumes equal variances. This is the default, when `vartype` is unspecified.
- 'unequal' — Does not assume equal variances. This is the Behrens-Fisher problem.

`vartype` must be a single string, even when x is a matrix or an N -dimensional array.

If `vartype` is 'equal', the test computes a pooled sample standard deviation using

$$s = \sqrt{\frac{(n-1)s_x^2 + (m-1)s_y^2}{n+m-2}}$$

where s_x and s_y are the sample standard deviations of x and y , respectively, and n and m are the sample sizes of x and y , respectively.

`h = ttest2(x,y,alpha,tail,vartype,dim)` works along dimension `dim` of x and y . Use `[]` to pass in default values for `alpha`, `tail`, or `vartype`.

`[h,p] = ttest2(...)` returns the p value of the test. The p value is the probability, under the null hypothesis, of observing a value as extreme or more extreme of the test statistic

$$t = \frac{\bar{x} - \bar{y}}{\sqrt{\frac{s_x^2}{n} + \frac{s_y^2}{m}}}$$

where \bar{x} and \bar{y} are the sample means, s_x and s_y are the sample standard deviations (replaced by the pooled standard deviation s in the default case where `vartype` is `'equal'`), and n and m are the sample sizes.

In the default case where `vartype` is `'equal'`, the test statistic, under the null hypothesis, has Student's t distribution with $n + m - 2$ degrees of freedom.

In the case where `vartype` is `'unequal'`, the test statistic, under the null hypothesis, has an approximate Student's t distribution with a number of degrees of freedom given by Satterthwaite's approximation.

`[h,p,ci] = ttest2(...)` returns a $100*(1 - \alpha)\%$ confidence interval on the difference of population means.

`[h,p,ci,stats] = ttest2(...)` returns structure `stats` with the following fields:

- `tstat` — Value of the test statistic
- `df` — Degrees of freedom of the test
- `sd` — Pooled sample standard deviation (in the default case where `vartype` is `'equal'`) or a vector with the sample standard deviations (in the case where `vartype` is `'unequal'`).

Examples

Simulate random samples of size 1000 from normal distributions with means 0 and 0.1, respectively, and standard deviations 1 and 2, respectively:

```
x = normrnd(0,1,1,1000);
y = normrnd(0.1,2,1,1000);
```

Test the null hypothesis that the samples come from populations with equal means, against the alternative that the means are unequal. Perform the test assuming unequal variances:

```
[h,p,ci] = ttest2(x,y,[],[],'unequal')
h =
     1
p =
```

ttest2

```
0.0102
ci =
-0.3227 -0.0435
```

The test rejects the null hypothesis at the default $\alpha = 0.05$ significance level. Under the null hypothesis, the probability of observing a value as extreme or more extreme of the test statistic, as indicated by the p value, is less than α . The 95% confidence interval on the mean of the difference does not contain 0.

This example will produce slightly different results each time it is run, because of the random sampling.

See Also

`ttest` | `ztest`

Purpose	Tree type
Syntax	<code>ttype = type(t)</code>
Description	<code>ttype = type(t)</code> returns the type of the tree <code>t</code> . <code>ttype</code> is 'regression' for regression trees and 'classification' for classification trees.

Examples

Create a classification tree for Fisher's iris data:

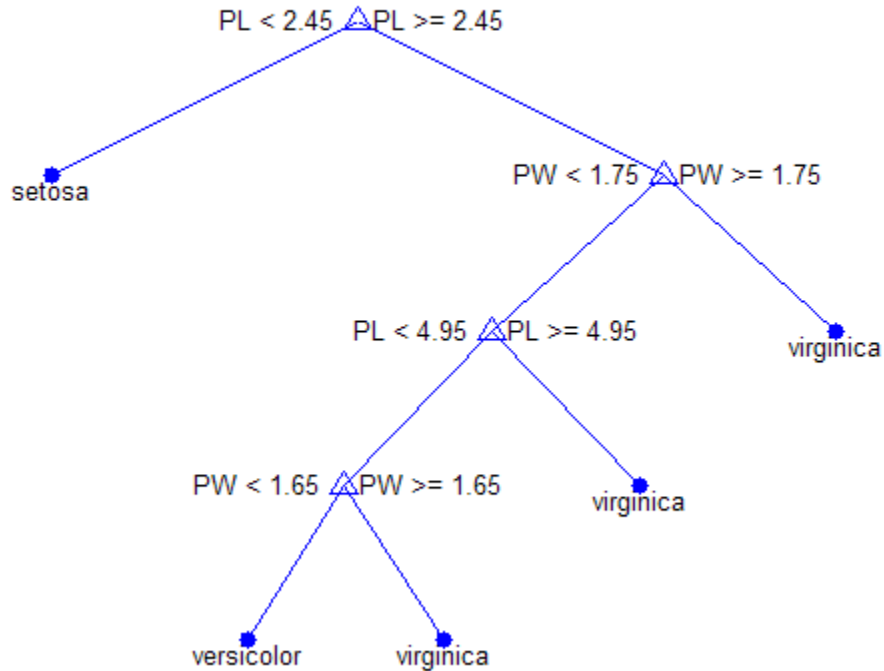
```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
6  if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(t)
```

classregtree.type

Click to display: Magnification: Pruning level:



```
ttype = type(t)  
ttype =  
classification
```

References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

See Also

classregtree

Purpose	Type of partition
Description	The type of validation partition. It is 'kfold', 'holdout', 'leaveout', or 'resubstitution'.
See Also	trainsize

grandset.Type property

Purpose Name of sequence on which point set P is based

Description P.Type returns a string that contains the name of the sequence on which the point set P is based, for example 'Sobol'. You cannot change the Type property for a point set.

Purpose	Convert categorical array to unsigned 8-bit integers
Syntax	<code>B = uint8(A)</code>
Description	<code>B = uint8(A)</code> converts the categorical array <code>A</code> to unsigned 8-bit integers. Each element of <code>B</code> contains the internal categorical level code for the corresponding element of <code>A</code> . Undefined elements of <code>A</code> are assigned the value 0 in <code>B</code> . If <code>A</code> contains more than <code>intmax('uint8')</code> levels, the internal codes will saturate to <code>intmax('uint8')</code> when cast to <code>int8</code> .
See Also	<code>double</code> <code>int8</code>

categorical.uint16

Purpose Convert categorical array to unsigned 16-bit integers

Syntax `B = uint16(A)`

Description `B = uint16(A)` converts the categorical array `A` to unsigned 16-bit integers. Each element of `B` contains the internal categorical level code for the corresponding element of `A`.

Undefined elements of `A` are assigned the value 0 in `B`.

See Also `double` | `int16`

Purpose	Convert categorical array to unsigned 32-bit integers
Syntax	<code>B = uint32(A)</code>
Description	<p><code>B = uint32(A)</code> converts the categorical array <code>A</code> to unsigned 32-bit integers. Each element of <code>B</code> contains the internal categorical level code for the corresponding element of <code>A</code>.</p> <p>Undefined elements of <code>A</code> are assigned the value 0 in <code>B</code>.</p>
See Also	<code>double</code> <code>int32</code>

categorical.uint64

Purpose Convert categorical array to unsigned 64-bit integers

Syntax `B = uint64(A)`

Description `B = uint64(A)` converts the categorical array `A` to unsigned 64-bit integers. Each element of `B` contains the internal categorical level code for the corresponding element of `A`.

Undefined elements of `A` are assigned the value 0 in `B`.

See Also `double` | `int64`

categorical.undeflabel property

Purpose Text label for undefined levels

Description Text label for undefined levels. Constant property with value '<undefined>'.

dataset.union

Purpose Set union for dataset array observations

Syntax

```
C = union(A,B)
C = union(A,B,vars)
C = union(A,B,vars,setOrder)
[C,iA,iB] = union( ___ )
```

Description

`C = union(A,B)` for dataset arrays `A` and `B` returns the combined set of observations from the two arrays, with repetitions removed. The observations in the dataset array `C` are sorted.

`C = union(A,B,vars)` returns the combined set of observations from the two arrays, with repetitions of unique combinations of the variables specified in `vars` removed. The observations in the dataset array `C` are sorted by those variables.

The values for variables not specified in `vars` for each observation in `C` are taken from the corresponding observation in `A` or `B`, or from `A` if there are common observations in both `A` and `B`. If there are multiple observations in `A` or `B` that correspond to an observation in `C`, those values are taken from the first occurrence.

`C = union(A,B,vars,setOrder)` returns the observations in `C` in the order specified by `setOrder`.

`[C,iA,iB] = union(___)` also returns index vectors `iA` and `iB` such that `C` is a sorted combination of the values `A(iA,:)` and `B(iB,:)`. If there are common observations in `A` and `B`, then `union` returns only the index from `A`, in `iA`. If there are repeated observations in `A` or `B`, then the index of the first occurrence is returned. You can use any of the previous input arguments.

Input Arguments

A,B Input dataset arrays.

vars Cell array of strings containing variable names or a vector of integers containing variable column numbers, indicating

the variables for which `union` removes repetitions of unique combinations of the variables.

Specify `vars` as `[]` to use its default value of all variables.

setOrder

Flag indicating the sorting order for the observations in `C`. The possible values of `setOrder` are:

'sorted'	Observations in <code>C</code> are in sorted order (default).
'stable'	Observations in <code>C</code> are in the same order that they appear in <code>A</code> , then <code>B</code> .

Output Arguments

C

Dataset array with the combined observations of `A` and `B`, with repetitions removed. `C` is in sorted order (by default), or the order specified by `setOrder`.

iA

Index vector, indicating the observations in `A` that contribute to the union. `iA` contains the index to the first occurrence of any repeated observations in `A`.

iB

Index vector, indicating the observations in `B` that contribute to the union. If there are common observations in `A` and `B`, then `union` returns only the index from `A`, in `iA`. `iB` contains the index to the first occurrence of any repeated observations in `B`.

Examples

Union of Two Dataset Arrays

Load sample data.

```
A = dataset('XLSFile','hospitalSmall.xlsx');
B = dataset('XLSFile','hospitalSmall.xlsx','Sheet',2);
```

dataset.union

```
[length(A) length(B)]
```

```
ans =
```

```
    14     8
```

The first dataset array, A, has 14 observations. The second dataset array, B, has 8 observations.

Return the union.

```
C = union(A,B);  
length(C)
```

```
ans =
```

```
    21
```

The union of the two dataset arrays has 21 observations, indicating that there was one observation replicated in A and B.

See Also

[dataset](#) | [intersect](#) | [ismember](#) | [setdiff](#) | [setxor](#) | [sortrows](#) | [unique](#) |

Related Examples

- “Create a Dataset Array from a File” on page 2-92
- “Merge Dataset Arrays” on page 2-122

Concepts

- “Dataset Arrays” on page 2-156

Purpose Unique observations in dataset array

Note In a future release, the behavior of `dataset.unique` will change to be consistent with the MATLAB function `unique`. This behavior change is optional in R2012a. For a demonstration of using the 'R2012a' flag to preview the future behavior, or the 'legacy' flag to preserve the current behavior in your existing code, see the documentation for `unique`.

Syntax

```
C = unique(A)
[C,ia,ic] = unique(A)
C = unique(A,vars)
[C,ia,ic] = unique(A,vars)
[...] = unique(A,vars,occurrence)
[...] = unique(...,'R2012a')
[...] = unique(...,'legacy')
[...] = unique(A,vars,setOrder)
```

Description `C = unique(A)` returns a copy of the dataset `A` that contains only the sorted unique observations. `A` must contain only variables whose class has a `unique` method, including:

- numeric
- character
- logical
- categorical
- cell arrays of strings

For a variable with multiple columns, its class's `unique` method must support the 'rows' flag.

`[C,ia,ic] = unique(A)` also returns index vectors `ia` and `ic` such that `C = A(ia,:)` and `A = C(ic,:)`.

dataset.unique

`C = unique(A,vars)` returns a dataset that contains only one observation for each unique combination of values for the variables in `A` specified in `vars`. `vars` is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector. `C` includes all variables from `A`. The values in `C` for the variables not specified in `vars` are taken from the last occurrence among observations in `A` with each unique combination of values for the variables specified in `vars`.

`[C,ia,ic] = unique(A,vars)` also returns index vectors `ia` and `ic` such that `C = A(ia,:)` and `A(:,vars) = C(ic,vars)`.

`[...] = unique(A,vars,occurrence)` specifies which index is returned in `ia` in the case of repeated observations in `A`. The default value is `occurrence='last'`, which returns the index of the last occurrence of each repeated observation in `A`. `occurrence='first'` returns the index of the first occurrence of each repeated observation in `A`. The values in `C` for variables not specified in `vars` are taken from the observations `A(ia,:)`. Specify `vars` as `[]` to use the default value of all variables.

`[...] = unique(...,'R2012a')` adopts the future behavior of `unique`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `vars`, or `occurrence`.

`[...] = unique(...,'legacy')` preserves the current behavior of `unique`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `vars`, or `occurrence`.

`[...] = unique(A,vars,setOrder)` returns the observations of `C` in a specific order. `setOrder='sorted'` returns the values of `C` in sorted order. `setOrder='stable'` returns the values of `C` in the same order as `A`. If there are repeated observations in `A`, then `ia` returns the index of the first occurrence of each repeated observation. Specify `vars` as `[]` to use the default value of all variables.

See Also

`dataset` | `set` | `subsasgn`

Purpose

Units of variables in data set

Description

A cell array of strings giving the units of the variables in the data set. This property may be empty, but if not empty, the number of strings must equal the number of variables. Any individual string may be empty for a variable that does not have units defined. The default is an empty cell array.

unidcdf

Purpose Discrete uniform cumulative distribution function

Syntax `P = unidcdf(X,N)`

Description `P = unidcdf(X,N)` computes the discrete uniform cdf at each of the values in `X` using the corresponding maximum observable value in `N`. `X` and `N` can be vectors, matrices, or multidimensional arrays that have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The maximum observable values in `N` must be positive integers.

The discrete uniform cdf is

$$p = F(x | N) = \frac{\text{floor}(x)}{N} I_{(1, \dots, N)}(x)$$

The result, p , is the probability that a single observation from the discrete uniform distribution with maximum N will be a positive integer less than or equal to x . The values x do not need to be integers.

Examples What is the probability of drawing a number 20 or less from a hat with the numbers from 1 to 50 inside?

```
probability = unidcdf(20,50)
probability =
    0.4000
```

See Also `cdf` | `unidpdf` | `unidinv` | `unidstat` | `unidrnd` | `mle`

How To • “Uniform Distribution (Discrete)” on page B-114

Purpose Discrete uniform inverse cumulative distribution function

Syntax `X = unidinv(P,N)`

Description `X = unidinv(P,N)` returns the smallest positive integer X such that the discrete uniform cdf evaluated at X is equal to or exceeds P . You can think of P as the probability of drawing a number as large as X out of a hat with the numbers 1 through N inside.

P and N can be vectors, matrices, or multidimensional arrays that have the same size, which is also the size of X . A scalar input for N or P is expanded to a constant array with the same dimensions as the other input. The values in P must lie on the interval $[0\ 1]$ and the values in N must be positive integers.

Examples

```
x = unidinv(0.7,20)
x =
    14
```

```
y = unidinv(0.7 + eps,20)
y =
    15
```

A small change in the first parameter produces a large jump in output. The cdf and its inverse are both step functions. The example shows what happens at a step.

See Also `icdf` | `unidcdf` | `unidpdf` | `unidstat` | `unidrnd`

How To

- “Uniform Distribution (Discrete)” on page B-114

unidpdf

Purpose Discrete uniform probability density function

Syntax `Y = unidpdf(X,N)`

Description `Y = unidpdf(X,N)` computes the discrete uniform pdf at each of the values in `X` using the corresponding maximum observable value in `N`. `X` and `N` can be vectors, matrices, or multidimensional arrays that have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `N` must be positive integers.

The discrete uniform pdf is

$$y = f(x | N) = \frac{1}{N} I_{(1, \dots, N)}(x)$$

You can think of `y` as the probability of observing any one number between 1 and `n`.

Examples For fixed `n`, the uniform discrete pdf is a constant.

```
y = unidpdf(1:6,10)
y =
    0.1000    0.1000    0.1000    0.1000    0.1000    0.1000
```

Now fix `x`, and vary `n`.

```
likelihood = unidpdf(5,4:9)
likelihood =
    0    0.2000    0.1667    0.1429    0.1250    0.1111
```

See Also `pdf` | `unidcdf` | `unidinv` | `unidstat` | `unidrnd`

How To • “Uniform Distribution (Discrete)” on page B-114

Purpose	Discrete uniform random numbers
Syntax	<pre>R = unidrnd(N) R = unidrnd(N,m,n,...) R = unidrnd(N,[m,n,...])</pre>
Description	<p>R = unidrnd(N) generates random numbers for the discrete uniform distribution with maximum N. The parameters in N must be positive integers. N can be a vector, a matrix, or a multidimensional array. The size of R is the size of N. The discrete uniform distribution arises from experiments equivalent to drawing a number from one to N out of a hat.</p> <p>R = unidrnd(N,m,n,...) or R = unidrnd(N,[m,n,...]) generates an m-by-n-by-... array. The N parameter can be a scalar or an array of the same size as R.</p>
Examples	<p>In the Massachusetts lottery, a player chooses a four-digit number. Generate random numbers for Monday through Saturday.</p> <pre>numbers = unidrnd(10000,1,6)-1 numbers = 4564 185 8214 4447 6154 7919</pre>
See Also	random unidpdf unidcdf unidinv unidstat
How To	<ul style="list-style-type: none">• “Uniform Distribution (Discrete)” on page B-114

unidstat

Purpose Discrete uniform mean and variance

Syntax `[M,V] = unidstat(N)`

Description `[M,V] = unidstat(N)` returns the mean and variance of the discrete uniform distribution with minimum value 1 and maximum value N .

The mean of the discrete uniform distribution with parameter N is $(N + 1)/2$. The variance is $(N^2 - 1)/12$.

Examples

```
[m,v] = unidstat(1:6)
m =
    1.0000    1.5000    2.0000    2.5000    3.0000    3.5000
v =
    0    0.2500    0.6667    1.2500    2.0000    2.9167
```

See Also `unidpdf` | `unidcdf` | `unidinv` | `unidrnd`

How To

- “Uniform Distribution (Discrete)” on page B-114

Purpose Continuous uniform cumulative distribution function

Syntax `P = unifcdf(X,A,B)`

Description `P = unifcdf(X,A,B)` computes the uniform cdf at each of the values in `X` using the corresponding lower endpoint (minimum), `A` and upper endpoint (maximum), `B`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant matrix with the same dimensions as the other inputs.

The uniform cdf is

$$p = F(x | a, b) = \frac{x - a}{b - a} I_{[a, b]}(x)$$

The standard uniform distribution has `A = 0` and `B = 1`.

Examples What is the probability that an observation from a standard uniform distribution will be less than 0.75?

```
probability = unifcdf(0.75)
probability =
    0.7500
```

What is the probability that an observation from a uniform distribution with `a = -1` and `b = 1` will be less than 0.75?

```
probability = unifcdf(0.75, -1, 1)
probability =
    0.8750
```

See Also `cdf` | `unifpdf` | `unifinv` | `unifstat` | `unifit` | `unifrnd`

How To • “Uniform Distribution (Continuous)” on page B-112

unifinv

Purpose Continuous uniform inverse cumulative distribution function

Syntax `X = unifinv(P,A,B)`

Description `X = unifinv(P,A,B)` computes the inverse of the uniform cdf with parameters A and B (the minimum and maximum values, respectively) at the corresponding probabilities in P. P, A, and B can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs.

The inverse of the uniform cdf is

$$x = F^{-1}(p | a, b) = a + p(a - b)I_{[0,1]}(p)$$

The standard uniform distribution has A = 0 and B = 1.

Examples What is the median of the standard uniform distribution?

```
median_value = unifinv(0.5)
median_value =
    0.5000
```

What is the 99th percentile of the uniform distribution between -1 and 1?

```
percentile = unifinv(0.99, -1, 1)
percentile =
    0.9800
```

See Also `icdf` | `unifcdf` | `unifpdf` | `unifstat` | `unifit` | `unifrnd`

How To • “Uniform Distribution (Continuous)” on page B-112

Purpose

Continuous uniform parameter estimates

Syntax

```
[ahat,bhat] = unifit(data)
[ahat,bhat,ACI,BCI] = unifit(data)
[ahat,bhat,ACI,BCI] = unifit(data,alpha)
```

Description

[ahat,bhat] = unifit(data) returns the maximum likelihood estimates (MLEs) of the parameters of the uniform distribution given the data in data.

[ahat,bhat,ACI,BCI] = unifit(data) also returns 95% confidence intervals, ACI and BCI, which are matrices with two rows. The first row contains the lower bound of the interval for each column of the matrix data. The second row contains the upper bound of the interval.

[ahat,bhat,ACI,BCI] = unifit(data,alpha) enables you to control of the confidence level alpha. For example, if alpha = 0.01 then ACI and BCI are 99% confidence intervals.

Examples

```
r = unifrnd(10,12,100,2);
[ahat,bhat,aci,bci] = unifit(r)
ahat =
    10.0154    10.0060
bhat =
    11.9989    11.9743
aci =
    9.9551    9.9461
    10.0154    10.0060
bci =
    11.9989    11.9743
    12.0592    12.0341
```

See Also

mle | unifpdf | unifcdf | unifinv | unifstat | unifrnd

How To

- “Uniform Distribution (Continuous)” on page B-112

unifpdf

Purpose Continuous uniform probability density function

Syntax `Y = unifpdf(X,A,B)`

Description `Y = unifpdf(X,A,B)` computes the continuous uniform pdf at each of the values in `X` using the corresponding lower endpoint (minimum), `A` and upper endpoint (maximum), `B`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array with the same dimensions as the other inputs. The parameters in `B` must be greater than those in `A`.

The continuous uniform distribution pdf is

$$y = f(x | a, b) = \frac{1}{b - a} I_{[a, b]}(x)$$

The standard uniform distribution has `A = 0` and `B = 1`.

Examples For fixed `a` and `b`, the uniform pdf is constant.

```
x = 0.1:0.1:0.6;  
y = unifpdf(x)  
y =  
    1    1    1    1    1    1
```

What if `x` is not between `a` and `b`?

```
y = unifpdf(-1,0,1)  
y =  
    0
```

See Also `pdf` | `unifcdf` | `unifinv` | `unifstat` | `unifit` | `unifrnd`

How To • “Uniform Distribution (Continuous)” on page B-112

Purpose Continuous uniform random numbers

Syntax

```
R = unifrnd(A,B)
R = unifrnd(A,B,m,n,...)
R = unifrnd(A,B,[m,n,...])
```

Description

`R = unifrnd(A,B)` returns an array `R` of random numbers generated from the continuous uniform distributions with lower and upper endpoints specified by `A` and `B`, respectively. If `A` and `B` are arrays, `R(i,j)` is generated from the distribution specified by the corresponding elements of `A` and `B`. If either `A` or `B` is a scalar, it is expanded to the size of the other input.

`R = unifrnd(A,B,m,n,...)` or `R = unifrnd(A,B,[m,n,...])` returns an `m`-by-`n`-by-... array. If `A` and `B` are scalars, all elements of `R` are generated from the same distribution. If either `A` or `B` is an array, they must be `m`-by-`n`-by-... .

Examples

Generate one random number each from the continuous uniform distributions on the intervals (0,1), (0,2), ..., (0,5):

```
a = 0; b = 1:5;
r1 = unifrnd(a,b)
r1 =
    0.8147    1.8116    0.3810    3.6535    3.1618
```

Generate five random numbers each from the same distributions:

```
B = repmat(b,5,1);
R = unifrnd(a,B)
R =
    0.0975    0.3152    0.4257    2.6230    3.7887
    0.2785    1.9412    1.2653    0.1428    3.7157
    0.5469    1.9143    2.7472    3.3965    1.9611
    0.9575    0.9708    2.3766    3.7360    3.2774
    0.9649    1.6006    2.8785    2.7149    0.8559
```

unifrnd

Generate five random numbers from the continuous uniform distribution on (0,2):

```
r2 = unifrnd(a,b(2),1,5)
```

```
r2 =
```

```
    1.4121    0.0637    0.5538    0.0923    0.1943
```

See Also

[rand](#) | [random](#) | [unifpdf](#) | [unifcdf](#) | [unifinv](#) | [unifstat](#) | [unifit](#)

How To

- “Uniform Distribution (Continuous)” on page B-112

Purpose Continuous uniform mean and variance

Syntax `[M,V] = unifstat(A,B)`

Description `[M,V] = unifstat(A,B)` returns the mean of and variance for the continuous uniform distribution using the corresponding lower endpoint (minimum), `A` and upper endpoint (maximum), `B`. Vector or matrix inputs for `A` and `B` must have the same size, which is also the size of `M` and `V`. A scalar input for `A` or `B` is expanded to a constant matrix with the same dimensions as the other input.

The mean of the continuous uniform distribution with parameters a and b is $(a + b)/2$, and the variance is $(a - b)^2/12$.

Examples

```
a = 1:6;
b = 2.*a;
[m,v] = unifstat(a,b)
m =
    1.5000    3.0000    4.5000    6.0000    7.5000    9.0000
v =
    0.0833    0.3333    0.7500    1.3333    2.0833    3.0000
```

See Also `unifpdf` | `unifcdf` | `unifinv` | `unifit` | `unifrnd`

How To • “Uniform Distribution (Continuous)” on page B-112

categorical.union

Purpose

Set union for categorical arrays

Note In a future release, the behavior of `categorical.union` will change to be consistent with the MATLAB function `union`. This behavior change is optional in R2012a. For a demonstration of using the 'R2012a' flag to preview the future behavior, or the 'legacy' flag to preserve the current behavior in your existing code, see the documentation for `union`.

Syntax

```
C = union(A,B)
[C,IA,IB] = union(A,B)
[...] = union(A,B,'rows')
[...] = union(...,'R2012a')
[...] = union(...,'legacy')
[...] = union(A,B,setOrder)
[...] = union(A,B,'rows',setOrder)
```

Description

`C = union(A,B)` for categorical vectors `A` and `B`, returns a categorical vector `C` containing the combined values from `A` and `B` with no repetitions. The result `C` is sorted. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs, as determined by their labels.

`[C,IA,IB] = union(A,B)` also returns index vectors `IA` and `IB` such that `C` is a sorted combination of the elements `A(IA)` and `B(IB)`. If there are common values in `A` and `B`, then the index is returned in `IB`. If there are repeated values in `A` or `B`, then the index of the last occurrence of each repeated value is returned.

`[...] = union(A,B,'rows')` for categorical matrices `A` and `B` with the same number of columns, returns the combined rows from the two matrices with no repetitions. The rows of the matrix `C` are sorted. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs. The optional outputs `IA` and `IB` are index vectors such that `C` is the sorted combination of the rows `C = A(IA,:)` and `C = B(IB,:)`.

`[...] = union(..., 'R2012a')` adopts the future behavior of `union`. You can specify the flag as the final argument with any previous syntax that accepts A, B, or 'rows'.

`[...] = union(..., 'legacy')` preserves the current behavior of `union`. You can specify the flag as the final argument with any previous syntax that accepts A, B, or 'rows'.

`[...] = union(A,B,setOrder)` and `[...] = union(A,B, 'rows', setOrder)` returns the observations of C in a specific order. `setOrder='sorted'` returns the values or rows of C in sorted order. `setOrder='stable'` returns the values or rows of C in the same order as A, then B. If A and B are row vectors, then C is also a row vector. Otherwise, C is a column vector. IA and IB are column vectors. If there are repeated common values in A or B, then the index of the first occurrence of each repeated value is returned.

See Also

`intersect` | `ismember` | `setdiff` | `setxor` | `unique`

categorical.unique

Purpose Unique values in categorical array

Note In a future release, the behavior of `categorical.unique` will change to be consistent with the MATLAB function `unique`. This behavior change is optional in R2012a. For a demonstration of using the 'R2012a' flag to preview the future behavior, or the 'legacy' flag to preserve the current behavior in your existing code, see the documentation for `unique`.

Syntax

```
C = unique(A)
[C,IA,IC] = unique(A)
[...] = unique(A,'rows')
[...] = unique(A,occurrence)
[...] = unique(A,'rows',occurrence)
[...] = unique(...,'R2012a')
[...] = unique(...,'legacy')
[...] = unique(A,setOrder)
[...] = unique(A,'rows',setOrder)
```

Description `C = unique(A)` returns a categorical array containing the same values as in `A` but with no repetitions. `C` is sorted by the order of `A`'s levels.

`[C,IA,IC] = unique(A)` also returns index vectors `IA` and `IC` such that `C = A(IA)` and `A = C(IC)`.

`[...] = unique(A,'rows')` for the categorical matrix `A` returns the unique rows of `A`. The rows of the matrix `C` are sorted by the order of `A`'s levels. The optional outputs `IA` and `IC` are index vectors such that `C = A(IA,:)` and `A = C(IC,:)`.

`[...] = unique(A,occurrence)` and `[...] = unique(A,'rows',occurrence)` specify which index is returned in `IA` in the case of repeated values or rows in `A`. The default value is `occurrence='last'`, which returns the index of the last occurrence of each repeated value or row in `A`. `occurrence='first'` returns the index of the first occurrence of each repeated value or row in `A`.

`[...] = unique(..., 'R2012a')` adopts the future behavior of `unique`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `'rows'`, or `occurrence`.

`[...] = unique(..., 'legacy')` preserves the current behavior of `unique`. You can specify the flag as the final argument with any previous syntax that accepts `A`, `'rows'`, or `occurrence`.

`[...] = unique(A, setOrder)` and `[...] = unique(A, 'rows', setOrder)` returns the values or rows of `C` in a specific order. `setOrder='sorted'` returns the values or rows of `C` in sorted order. `setOrder='stable'` returns the values or rows of `C` in the same order as `A`. If `A` is a row vector, then `C` is also a row vector. Otherwise, `C` is a column vector. `IA` and `IC` are column vectors. If there are repeated values in `A`, then `IA` returns the index of the first occurrence of each repeated value.

See Also

`intersect` | `ismember` | `setdiff` | `setxor` | `union`

dataset.unstack

Purpose Unstack data from single variable into multiple variables

Syntax

```
wide = unstack(tall,datavar,indvar)
[wide,itall] = unstack(tall,datavar,indvar)
wide = unstack(tall,datavar,indvar,'Parameter',value)
```

Description `wide = unstack(tall,datavar,indvar)` converts a dataset array `tall` to an equivalent dataset array `wide` that is in wide format, by unstacking a single variable in `tall` into multiple variables in `wide`. In general `wide` contains more variables, but fewer observations, than `tall`.

`datavar` specifies the data variable in `tall` to unstack. `indvar` specifies an indicator variable in `tall` that determines which variable in `wide` each value in `datavar` is unstacked into. `unstack` treats the remaining variables in `tall` as grouping variables. Each unique combination of their values defines a group of observations in `tall` that will be unstacked into a single observation in `wide`.

`unstack` creates `m` data variables in `wide`, where `m` is the number of group levels in `indvar`. The values in `indvar` indicate which of those `m` variables receive which values from `datavar`. The `j`-th data variable in `wide` contains the values from `datavar` that correspond to observations whose `indvar` value was the `j`-th of the `m` possible levels. Elements of those `m` variables for which no corresponding data value in `tall` exists contain a default value.

`datavar` is a positive integer, a variable name, or a logical vector containing a single true value. `indvar` is a positive integer, a variable name, or a logical vector containing a single true value.

`[wide,itall] = unstack(tall,datavar,indvar)` returns an index vector `itall` indicating the correspondence between observations in `wide` and those in `tall`. For each observation in `wide`, `itall` contains the index of the first in the corresponding group of observations in `tall`.

For more information on grouping variables, see “Grouping Variables” on page 2-72.

Input Arguments

`wide = unstack(tall, datavar, indvar, 'Parameter', value)` uses the following parameter name/value pairs to control how `unstack` converts variables in `tall` to variables in `wide`:

'GroupVars '	Grouping variables in <code>tall</code> that define groups of observations. <code>groupvars</code> is a positive integer, a vector of positive integers, a variable name, a cell array containing one or more variable names, or a logical vector. The default is all variables in <code>tall</code> not listed in <code>datavar</code> or <code>indvar</code> .
'NewDataVarNames '	A cell array of strings containing names for the data variables <code>unstack</code> should create in <code>wide</code> . Default is the group names of the grouping variable specified in <code>indvar</code> .
'AggregationFun '	A function handle that accepts a subset of values from <code>datavar</code> and returns a single value. <code>stack</code> applies this function to observations from the same group that have the same value of <code>indvar</code> . The function must aggregate the data values into a single value, and in such cases it is not possible to recover <code>tall</code> from <code>wide</code> using <code>stack</code> . The default is <code>@sum</code> for numeric data variables. For non-numeric variables, there is no default, and you must specify 'AggregationFun' if multiple observations in the same group have the same values of <code>indvar</code> .
'ConstVars '	Variables in <code>tall</code> to copy to <code>wide</code> without unstacking. The values for these variables in <code>wide</code> are taken from the first observation in each group in <code>tall</code> , so these variables should typically be constant within each group. <code>ConstVars</code> is a positive integer, a vector of positive integers, a variable name, a cell array

containing one or more variable names, or a logical vector. The default is no variables.

You can also specify more than one data variable in `tall`, each of which becomes a set of `m` variables in `wide`. In this case, specify `datavar` as a vector of positive integers, a cell array containing variable names, or a logical vector. You may specify only one variable with `indvar`. The names of each set of data variables in `wide` are the name of the corresponding data variable in `tall` concatenated with the names specified in `'NewDataVarNames'`. The function specified in `'AggregationFun'` must return a value with a single row.

Examples

Convert a "wide format" data set to "tall format", and then back to a different "wide format":

```
load flu

% FLU has a 'Date' variable, and 10 variables for estimated
% influenza rates (in 9 different regions, estimated from
% Google searches, plus a nationwide estimate from the
% CDC). Combine those 10 variables into a "tall" array that
% has a single data variable, 'FluRate', and an indicator
% variable, 'Region', that says which region each estimate
% is from.
[flu2,iflu] = stack(flu, 2:11, 'NewDataVarName','FluRate', ...
    'IndVarName','Region')

% The second observation in FLU is for 10/16/2005. Find the
% observations in FLU2 that correspond to that date.
flu(2,:)
flu2(iflu==2,:);

% Use the 'Date' variable from that tall array to split
% 'FluRate' into 52 separate variables, each containing the
% estimated influenza rates for each unique date. The new
% "wide" array has one observation for each region. In
% effect, this is the original array FLU "on its side".
dateNames = cellstr(datestr(flu.Date,'mmm_DD_YYYY'));
```

```
[flu3,iflu2] = unstack(flu2, 'FluRate', 'Date', ...  
    'NewDataVarNames',dateNames)  
  
% Since observations in FLU3 represent regions, IFLU2  
% indicates the first occurrence in FLU2 of each region.  
flu2(iflu2,:)
```

See Also

`dataset.stack` | `dataset.join`

How To

- “Grouping Variables” on page 2-72

paretotails.upperparams

Purpose Upper Pareto tails parameters

Syntax `params = upperparams(obj)`

Description `params = upperparams(obj)` returns the 2-element vector `params` of shape and scale parameters, respectively, of the upper tail of the Pareto tails object `obj`. `upperparams` does not return a location parameter.

Examples Fit Pareto tails to a *t* distribution at cumulative probabilities 0.1 and 0.9:

```
t = trnd(3,100,1);  
obj = paretotails(t,0.1,0.9);
```

```
lowerparams(obj)  
ans =  
    -0.1901    1.1898  
upperparams(obj)  
ans =  
    0.3646    0.5103
```

See Also `paretotails` | `lowerparams`

Purpose

Variable containing additional information associated with data set

Description

Any variable containing additional information to be associated with the data set. The default is an empty array.

ProbDistUnivParam.var

Purpose	Return variance of ProbDistUnivParam object	
Syntax	$V = \text{var}(PD)$	
Description	$V = \text{var}(PD)$ returns V , the variance of the ProbDistUnivParam object PD .	
Input Arguments	PD	An object of the class ProbDistUnivParam.
Output Arguments	V	The variance of the ProbDistUnivParam object PD .
See Also	var	

dataset.VarDescription property

Purpose

Cell array of strings giving descriptions of variables in data set

Description

A cell array of strings giving the descriptions of the variables in the data set. This property may be empty, but if not empty, the number of strings must equal the number of variables. Any individual string may be empty for a variable that does not have a description defined. The default is an empty cell array.

classregtree.varimportance

Purpose Compute embedded estimates of input feature importance

Syntax `imp = varimportance(t)`

Description `imp = varimportance(t)` computes estimates of input feature importance for tree `t` by summing changes in the risk due to splits on every feature. The returned vector `imp` has one element for each input variable in the data used to train this tree. At each node, the risk is estimated as node impurity if impurity was used to split nodes and node error otherwise. This risk is weighted by the node probability. Variable importance associated with this split is computed as the difference between the risk for the parent node and the total risk for the two children.

See Also `risk`

Purpose

Cell array giving names of variables in data set

Description

A cell array of nonempty, distinct strings giving the names of the variables in the data set. The number of strings must equal the number of variables. The default is the cell array of string names for the variables used to create the data set.

TreeBagger.VarNames property

Purpose Variable names

Description The VarNames property is a cell array containing the names of the predictor variables (features). `TreeBagger` takes these names from the optional 'names' parameter. The default names are 'x1', 'x2', etc.

Purpose

Chi-square variance test

Syntax

```
H = vartest(X,V)
H = vartest(X,V,alpha)
H = vartest(X,V,alpha,tail)
[H,P] = vartest(...)
[H,P,CI] = vartest(...)
[H,P,CI,STATS] = vartest(...)
[...] = vartest(X,V,alpha,tail,dim)
```

Description

`H = vartest(X,V)` performs a chi-square test of the hypothesis that the data in the vector `X` comes from a normal distribution with variance `V`, against the alternative that `X` comes from a normal distribution with a different variance. The result is `H = 0` if the null hypothesis (variance is `V`) cannot be rejected at the 5% significance level, or `H = 1` if the null hypothesis can be rejected at the 5% level.

`X` may also be a matrix or an `n`-dimensional array. For matrices, `vartest` performs separate tests along each column of `X`, and returns a row vector of results. For `n`-dimensional arrays, `vartest` works along the first nonsingleton dimension of `X`. `V` must be a scalar.

`H = vartest(X,V,alpha)` performs the test at the significance level $(100*\alpha)\%$. `alpha` has a default value of 0.05 and must be a scalar.

`H = vartest(X,V,alpha,tail)` performs the test against the alternative hypothesis specified by `tail`, where `tail` is a single string from the following choices:

- 'both' — Variance is not `V` (two-tailed test). This is the default.
- 'right' — Variance is greater than `V` (right-tailed test).
- 'left' — Variance is less than `V` (left-tailed test).

`[H,P] = vartest(...)` returns the p value, i.e., the probability of observing the given result, or one more extreme, by chance if the null hypothesis is true. Small values of `P` cast doubt on the validity of the null hypothesis.

vartest

`[H,P,CI] = vartest(...)` returns a $100 \cdot (1 - \alpha)\%$ confidence interval for the true variance.

`[H,P,CI,STATS] = vartest(...)` returns the structure `STATS` with the following fields:

- `'chisqstat'` — Value of the test statistic
- `'df'` — Degrees of freedom of the test

`[...] = vartest(X,V,alpha,tail,dim)` works along dimension `dim` of `X`. Pass in `[]` for `alpha` or `tail` to use their default values.

Examples

Determine whether the standard deviation is significantly different from 7?

```
load carsmall
```

```
[h,p,ci] = vartest(MPG,7^2)
```

See Also

[ttest](#) | [ztest](#) | [vartest2](#)

Purpose

Two-sample F -test for equal variances

Syntax

```
H = vartest2(X,Y)
H = vartest2(X,Y,alpha)
H = vartest2(X,Y,alpha,tail)
[H,P] = vartest2(...)
[H,P,CI] = vartest2(...)
[H,P,CI,STATS] = vartest2(...)
[...] = vartest2(X,Y,alpha,tail,dim)
```

Description

`H = vartest2(X,Y)` performs an F test of the hypothesis that two independent samples, in the vectors X and Y , come from normal distributions with the same variance, against the alternative that they come from normal distributions with different variances. The result is $H = 0$ if the null hypothesis (variances are equal) cannot be rejected at the 5% significance level, or $H = 1$ if the null hypothesis can be rejected at the 5% level. X and Y can have different lengths. X and Y can also be matrices or n -dimensional arrays.

For matrices, `vartest2` performs separate tests along each column, and returns a vector of results. X and Y must have the same number of columns. For n -dimensional arrays, `vartest2` works along the first nonsingleton dimension. X and Y must have the same size along all the remaining dimensions.

`H = vartest2(X,Y,alpha)` performs the test at the significance level $(100*\alpha)\%$. `alpha` must be a scalar.

`H = vartest2(X,Y,alpha,tail)` performs the test against the alternative hypothesis specified by `tail`, where `tail` is one of the following single strings:

- 'both' — Variance is not Y (two-tailed test). This is the default.
- 'right' — Variance is greater than Y (right-tailed test).
- 'left' — Variance is less than Y (left-tailed test).

`[H,P] = vartest2(...)` returns the p value, i.e., the probability of observing the given result, or one more extreme, by chance if the null

vartest2

hypothesis is true. Small values of P cast doubt on the validity of the null hypothesis.

`[H,P,CI] = vartest2(...)` returns a $100 \cdot (1 - \alpha)\%$ confidence interval for the true variance ratio $\text{var}(X)/\text{var}(Y)$.

`[H,P,CI,STATS] = vartest2(...)` returns a structure with the following fields:

- 'fstat' — Value of the test statistic
- 'df1' — Numerator degrees of freedom of the test
- 'df2' — Denominator degrees of freedom of the test

`[...] = vartest2(X,Y,alpha,tail,dim)` works along dimension `dim` of `X`. To pass in the default values for `alpha` or `tail` use `[]`.

Examples

Is the variance significantly different for two model years, and what is a confidence interval for the ratio of these variances?

```
load carsmall
```

```
[H,P,CI] =  
vartest2(MPG(Model_Year==82),MPG(Model_Year==76))
```

See Also

[ansaribradley](#) | [vartest](#) | [vartestn](#) | [ttest2](#)

Purpose Bartlett multiple-sample test for equal variances

Syntax

```
vartestn(X)
vartestn(X,group)
p = vartestn(...)
[p,STATS] = vartestn(...)
[...] = vartestn(...,displayopt)
[...] = vartestn(...,testtype)
```

Description `vartestn(X)` performs Bartlett's test for equal variances for the columns of the matrix `X`. This is a test of the null hypothesis that the columns of `X` come from normal distributions with the same variance, against the alternative that they come from normal distributions with different variances. The result is a display of a box plot of the groups, and a summary table of statistics.

`vartestn(X,group)` requires a vector `X`, and a `group` argument that is a categorical variable, vector, string array, or cell array of strings with one row for each element of `X`. The `X` values corresponding to the same value of `group` are placed in the same group. The function tests for equal variances across groups.

`vartestn` treats NaNs as missing values and ignores them.

`p = vartestn(...)` returns the p -value, i.e., the probability of observing the given result, or one more extreme, by chance if the null hypothesis of equal variances is true. Small values of `p` cast doubt on the validity of the null hypothesis.

`[p,STATS] = vartestn(...)` returns a structure with the following fields:

- 'chistat' — Value of the test statistic
- 'df' — Degrees of freedom of the test

`[...] = vartestn(...,displayopt)` determines if a box plot and table are displayed. `displayopt` may be 'on' (the default) or 'off' .

`[...] = vartestn(...,testtype)` sets the test type. When `testtype` is 'classical', `vartestn` performs Bartlett's test. When

vartestn

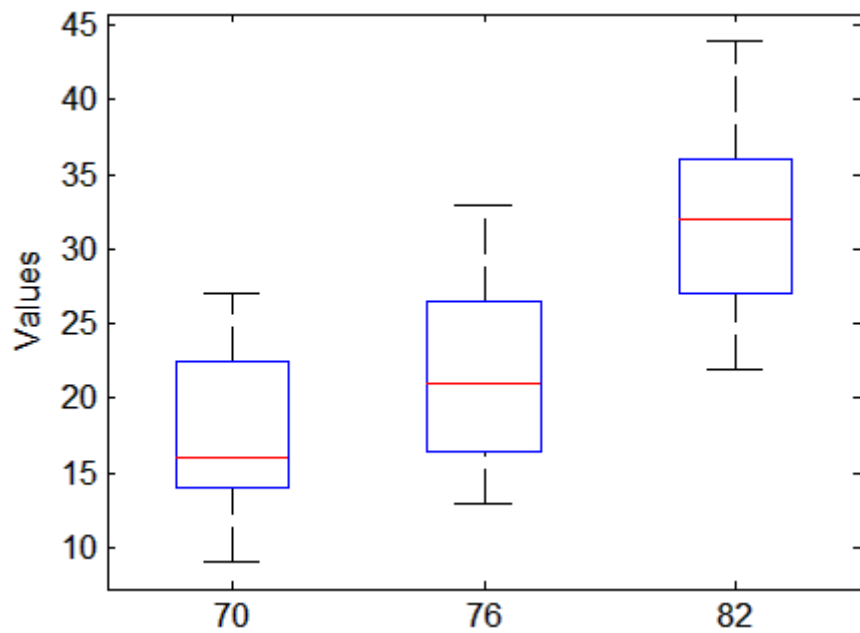
testtype is 'robust', *vartestn* performs Levene's test using squared deviations from the group means in place of Bartlett's test. This is a useful alternative when the sample distributions are not normal, and especially when they are prone to outliers. For this test the *STATS* output structure has a field named 'fstat' containing the test statistic, and 'df1' and 'df2' containing its numerator and denominator degrees of freedom.

Examples

Does the variance of mileage measurements differ significantly from one model year to another?

```
load carsmall
p = vartestn(MPG,Model_Year)
p =
    0.8327
```

Group	Count	Mean	Std Dev
70	29	17.6897	5.33923
76	34	21.5735	5.8893
82	31	31.7097	5.39255
Pooled	94	23.7181	5.562
Bartlett's statistic	0.36619		
Degrees of freedom	2		
p-value	0.83269		

**See Also**

vartest | vartest2 | anova1

How To

- “Grouping Variables” on page 2-72

categorical.vertcat

Purpose Vertical concatenation for categorical arrays

Syntax `C = vertcat(dim,A,B,...)`
`C = vertcat(A,B)`

Description `C = vertcat(dim,A,B,...)` vertically concatenates the categorical arrays `A,B,...`. For matrices, all inputs must have the same number of rows. For n-D arrays, all inputs must have the same sizes except in the second dimension. The set of categorical levels for `C` is the sorted union of the sets of levels of the inputs, as determined by their labels.

`C = vertcat(A,B)` is called for the syntax `[A B]`.

See Also `cat` | `horzcat`

Purpose Vertical concatenation for dataset arrays

Syntax `ds = vertcat(ds1, ds2, ...)`

Description `ds = vertcat(ds1, ds2, ...)` vertically concatenates the dataset arrays `ds1`, `ds2`, Observation names, when present, must be unique across datasets. `vertcat` fills in default observation names for the output when some of the inputs have names and some do not.

Variable names for all dataset arrays must be identical except for order. `vertcat` concatenates by matching variable names. `vertcat` assigns values for the "per-variable" properties (e.g., `Units` and `VarDescription`) in `ds` from the corresponding property values in `ds1`.

See Also `cat` | `horzcat`

classregtree.view

Purpose Plot tree

Syntax `view(t)`
`view(t,param1,val1,param2,val2,...)`

Description `view(t)` displays the decision tree `t` as computed by `classregtree` in a figure window. Each branch in the tree is labeled with its decision rule, and each terminal node is labeled with the predicted value for that node. Click any node to get more information about it. The information displayed is specified by the **Click to display** pop-up menu at the top of the figure.

`view(t,param1,val1,param2,val2,...)` specifies optional parameter name/value pairs:

- 'names' — A cell array of names for the predictor variables, in the order in which they appear in the matrix `X` from which the tree was created. (See `classregtree`.)
- 'prunelevel' — Initial pruning level to display.

For each branch node, the left child node corresponds to the points that satisfy the condition, and the right child node corresponds to the points that do not satisfy the condition.

Examples

Create a classification tree for Fisher's iris data:

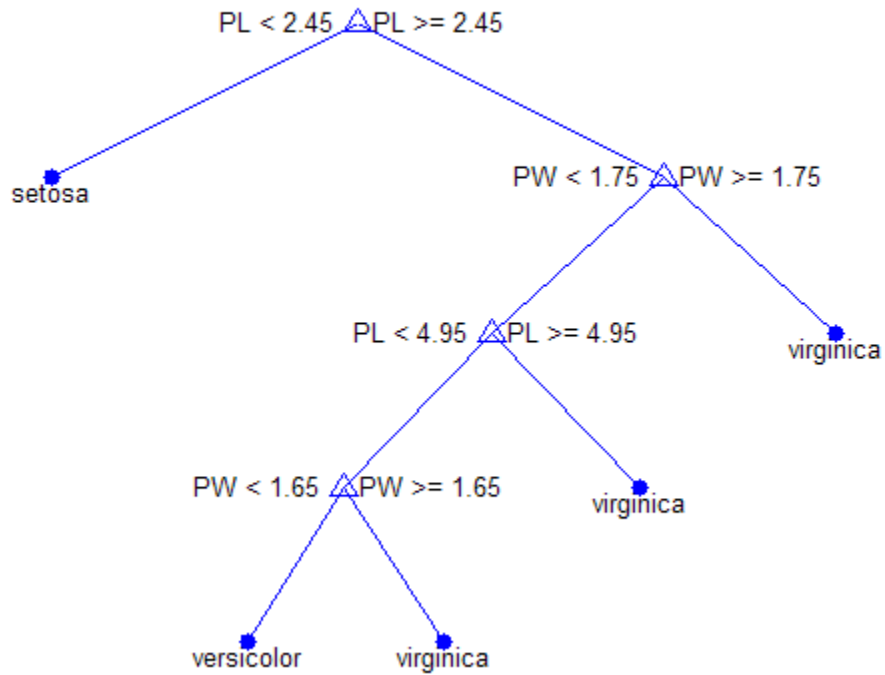
```
load fisheriris;

t = classregtree(meas,species,...
                'names',{'SL' 'SW' 'PL' 'PW'})
t =
Decision tree for classification
1  if PL<2.45 then node 2 elseif PL>=2.45 then node 3 else setosa
2  class = setosa
3  if PW<1.75 then node 4 elseif PW>=1.75 then node 5 else versicolor
4  if PL<4.95 then node 6 elseif PL>=4.95 then node 7 else versicolor
5  class = virginica
```

```
6 if PW<1.65 then node 8 elseif PW>=1.65 then node 9 else versicolor
7 class = virginica
8 class = versicolor
9 class = virginica

view(t)
```

Click to display: Magnification: Pruning level:



References

[1] Breiman, L., J. Friedman, R. Olshen, and C. Stone. *Classification and Regression Trees*. Boca Raton, FL: CRC Press, 1984.

classregtree.view

See Also

`classregtree` | `eval` | `prune` | `test`

Purpose

View tree

Syntax

```
view(tree)
view(tree,Name,Value)
```

Description

`view(tree)` returns a text description of `tree`, a decision tree.
`view(tree,Name,Value)` describes `tree` with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments**tree**

A classification tree or compact classification tree created by `ClassificationTree.fit` or `compact`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

mode

String describing the display of `tree`, either 'graph' or 'text'. 'graph' opens a GUI displaying `tree`, and containing controls for querying the tree. 'text' sends output to the Command Window describing `tree`.

Default: 'text'

Examples

View the classification tree for Fisher's iris model in both textual and graphical displays:

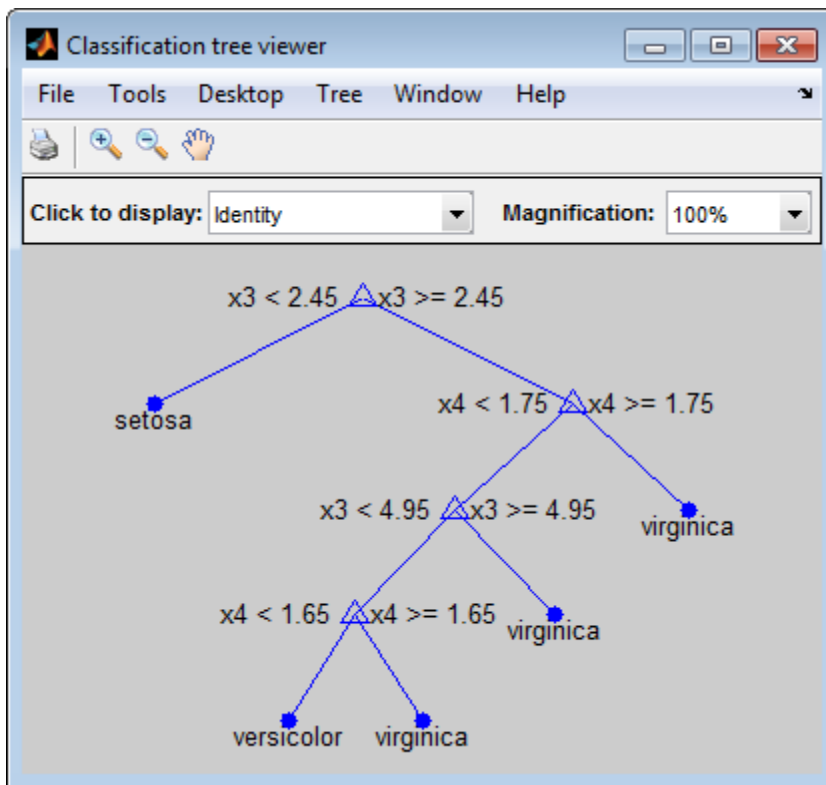
```
load fisheriris
tree = ClassificationTree.fit(meas,species);
view(tree)
```

CompactClassificationTree.view

```
Decision tree for classification
1  if x3<2.45 then node 2 elseif x3>=2.45 then node 3 else setosa
2  class = setosa
3  if x4<1.75 then node 4 elseif x4>=1.75 then node 5 else versicolor
4  if x3<4.95 then node 6 elseif x3>=4.95 then node 7 else versicolor
5  class = virginica
6  if x4<1.65 then node 8 elseif x4>=1.65 then node 9 else versicolor
7  class = virginica
8  class = versicolor
9  class = virginica

view(tree,'mode','graph')
```

CompactClassificationTree.view



See Also

ClassificationTree

CompactRegressionTree.view

Purpose View tree

Syntax `view(tree)`
`view(tree,Name,Value)`

Description `view(tree)` returns a text description of `tree`, a decision tree.
`view(tree,Name,Value)` describes `tree` with additional options specified by one or more `Name,Value` pair arguments.

Input Arguments **tree**
A regression tree or compact regression tree created by `RegressionTree.fit` or `compact`.

Name-Value Pair Arguments

Specify optional comma-separated pairs of `Name,Value` arguments, where `Name` is the argument name and `Value` is the corresponding value. `Name` must appear inside single quotes (' '). You can specify several name and value pair arguments in any order as `Name1,Value1,...,NameN,ValueN`.

mode

String describing the display of `tree`, either 'graph' or 'text'. 'graph' opens a GUI displaying `tree`, and containing controls for querying the tree. 'text' sends output to the Command Window describing `tree`.

Default: 'text'

Examples View a regression tree for the `carsmall` data in both textual and graphical displays:

```
load carsmall
tree = RegressionTree.fit([Weight, Cylinders],MPG,...
    'categoricalpredictors',2,'MinParent',20,...
    'PredictorNames',{'W','C'});
```

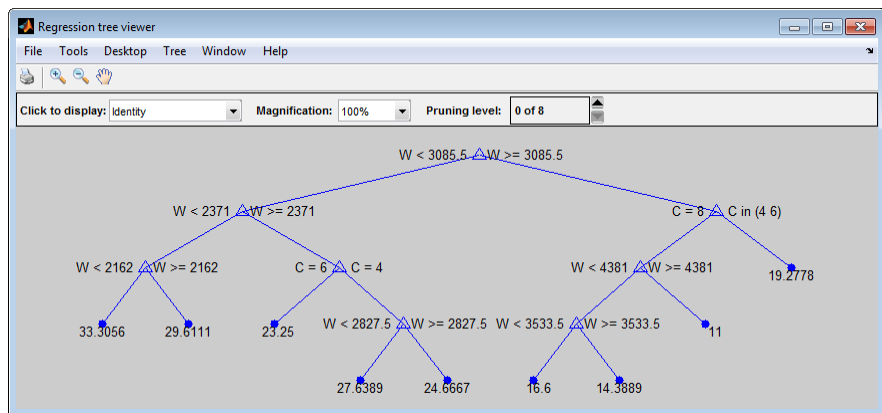
CompactRegressionTree.view

```
view(tree)
```

Decision tree for regression

```
1 if W<3085.5 then node 2 elseif W>=3085.5 then node 3 else 23.7181
2 if W<2371 then node 4 elseif W>=2371 then node 5 else 28.7931
3 if C=8 then node 6 elseif C in {4 6} then node 7 else 15.5417
4 if W<2162 then node 8 elseif W>=2162 then node 9 else 32.0741
5 if C=6 then node 10 elseif C=4 then node 11 else 25.9355
6 if W<4381 then node 12 elseif W>=4381 then node 13 else 14.2963
7 fit = 19.2778
8 fit = 33.3056
9 fit = 29.6111
10 fit = 23.25
11 if W<2827.5 then node 14 elseif W>=2827.5 then node 15 else 27.2143
12 if W<3533.5 then node 16 elseif W>=3533.5 then node 17 else 14.8696
13 fit = 11
14 fit = 27.6389
15 fit = 24.6667
16 fit = 16.6
17 fit = 14.3889
```

```
view(tree,'mode','graph')
```



CompactRegressionTree.view

See Also

[RegressionTree](#)

Purpose Weibull cumulative distribution function

Syntax `P = wblcdf(X,A,B)`
`[P,PLO,PUP] = wblcdf(X,A,B,PCOV,alpha)`

Description `P = wblcdf(X,A,B)` computes the cdf of the Weibull distribution with scale parameter `A` and shape parameter `B`, at each of the values in `X`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other inputs. The default values for `A` and `B` are both 1. The parameters `A` and `B` must be positive.

`[P,PLO,PUP] = wblcdf(X,A,B,PCOV,alpha)` returns confidence bounds for `P` when the input parameters `A` and `B` are estimates. `PCOV` is the 2-by-2 covariance matrix of the estimated parameters. `alpha` has a default value of 0.05, and specifies 100(1 - `alpha`)% confidence bounds. `PLO` and `PUP` are arrays of the same size as `P` containing the lower and upper confidence bounds.

The function `wblcdf` computes confidence bounds for `P` using a normal approximation to the distribution of the estimate

$$\hat{b}(\log x - \log \hat{a})$$

and then transforms those bounds to the scale of the output `P`. The computed bounds give approximately the desired confidence level when you estimate `mu`, `sigma`, and `PCOV` from large samples, but in smaller samples other methods of computing the confidence bounds might be more accurate.

The Weibull cdf is

$$p = F(x | a, b) = \int_0^x b a^{-b} t^{b-1} e^{-\left(\frac{t}{a}\right)^b} dt = 1 - e^{-\left(\frac{x}{a}\right)^b} I_{(0, \infty)}(x)$$

Examples What is the probability that a value from a Weibull distribution with parameters `a = 0.15` and `b = 0.8` is less than 0.5?

wblcdf

```
probability = wblcdf(0.5, 0.15, 0.8)
probability =
    0.9272
```

How sensitive is this result to small changes in the parameters?

```
[A, B] = meshgrid(0.1:0.05:0.2,0.2:0.05:0.3);
probability = wblcdf(0.5, A, B)
probability =
    0.7484    0.7198    0.6991
    0.7758    0.7411    0.7156
    0.8022    0.7619    0.7319
```

See Also

[cdf](#) | [wblpdf](#) | [wblinv](#) | [wblstat](#) | [wblfit](#) | [wbllike](#) | [wblrnd](#)

How To

- “Weibull Distribution” on page B-116

Purpose

Weibull parameter estimates

Syntax

```

parmhat = wblfit(data)
[parmhat,parmci] = wblfit(data)
[parmhat,parmci] = wblfit(data,alpha)
[...] = wblfit(data,alpha,censoring)
[...] = wblfit(data,alpha,censoring,freq)
[...] = wblfit(...,options)

```

Description

`parmhat = wblfit(data)` returns the maximum likelihood estimates, `parmhat`, of the parameters of the Weibull distribution given the values in the vector `data`, which must be positive. `parmhat` is a two-element row vector: `parmhat(1)` estimates the Weibull parameter a , and `parmhat(2)` estimates the Weibull parameter b , in the pdf

$$y = f(x | a, b) = ba^{-b} x^{b-1} e^{-\left(\frac{x}{a}\right)^b} I_{(0, \infty)}(x)$$

`[parmhat,parmci] = wblfit(data)` returns 95% confidence intervals for the estimates of a and b in the 2-by-2 matrix `parmci`. The first row contains the lower bounds of the confidence intervals for the parameters, and the second row contains the upper bounds of the confidence intervals.

`[parmhat,parmci] = wblfit(data,alpha)` returns $100(1 - \text{alpha})\%$ confidence intervals for the parameter estimates.

`[...] = wblfit(data,alpha,censoring)` accepts a Boolean vector, `censoring`, of the same size as `data`, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.

`[...] = wblfit(data,alpha,censoring,freq)` accepts a frequency vector, `freq`, of the same size as `data`. The vector `freq` typically contains integer frequencies for the corresponding elements in `data`, but can contain any non-negative values. Pass in `[]` for `alpha`, `censoring`, or `freq` to use their default values.

[...] = wblfit(...,options) accepts a structure, options, that specifies control parameters for the iterative algorithm the function uses to compute maximum likelihood estimates. The Weibull fit function accepts an options structure that can be created using the function statset. Enter statset ('wblfit') to see the names and default values of the parameters that lognfit accepts in the options structure. See the reference page for statset for more information about these options.

Examples

```
data = wblrnd(0.5,0.8,100,1);
[parmhat, parmci] = wblfit(data)
parmhat =
    0.5861    0.8567
parmci =
    0.4606    0.7360
    0.7459    0.9973
```

See Also

mle | wbllike | wblpdf | wblcdf | wblinv | wblstat | wblrnd

How To

- “Weibull Distribution” on page B-116

Purpose

Weibull inverse cumulative distribution function

Syntax

```
X = wblinv(P,A,B)
[X,XLO,XUP] = wblinv(P,A,B,PCOV,alpha)
```

Description

`X = wblinv(P,A,B)` returns the inverse cumulative distribution function (cdf) for a Weibull distribution with scale parameter `A` and shape parameter `B`, evaluated at the values in `P`. `P`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other inputs. The default values for `A` and `B` are both 1.

`[X,XLO,XUP] = wblinv(P,A,B,PCOV,alpha)` returns confidence bounds for `X` when the input parameters `A` and `B` are estimates. `PCOV` is a 2-by-2 matrix containing the covariance matrix of the estimated parameters. `alpha` has a default value of 0.05, and specifies $100(1 - \text{alpha})\%$ confidence bounds. `XLO` and `XUP` are arrays of the same size as `X` containing the lower and upper confidence bounds.

The function `wblinv` computes confidence bounds for `X` using a normal approximation to the distribution of the estimate

$$\log a + \frac{\log q}{b}$$

where q is the P th quantile from a Weibull distribution with scale and shape parameters both equal to 1. The computed bounds give approximately the desired confidence level when you estimate μ , σ , and `PCOV` from large samples, but in smaller samples other methods of computing the confidence bounds might be more accurate.

The inverse of the Weibull cdf is

$$x = F^{-1}(p | a, b) = -a [\ln(1 - p)]^{1/b} I_{[0,1]}(p)$$

Examples

The lifetimes (in hours) of a batch of light bulbs has a Weibull distribution with parameters $a = 200$ and $b = 6$.

Find the median lifetime of the bulbs:

```
life = wblinv(0.5, 200, 6)
life =
    188.1486
```

Generate 100 random values from this distribution, and estimate the 90th percentile (with confidence bounds) from the random sample

```
x = wblrnd(200,6,100,1);
p = wblfit(x)
[nlogl,pcov] = wbllike(p,x)
[q90,q90lo,q90up] = wblinv(0.9,p(1),p(2),pcov)
p =
```

```
    204.8918    6.3920
```

```
nlogl =
```

```
    496.8915
```

```
pcov =
```

```
    11.3392    0.5233
     0.5233    0.2573
```

```
q90 =
```

```
    233.4489
```

```
q90lo =
```

226.0092

q90up =

241.1335

See Also

icdf | wblcdf | wblpdf | wblstat | wblfit | wbllike | wblrnd

How To

- “Weibull Distribution” on page B-116

wbllike

Purpose Weibull negative log-likelihood

Syntax

```
nlogL = wbllike(params,data)
[logL,AVAR] = wbllike(params,data)
[...] = wbllike(params,data,censoring)
[...] = wbllike(params,data,censoring,freq)
```

Description `nlogL = wbllike(params,data)` returns the Weibull log-likelihood. `params(1)` is the scale parameter, `A`, and `params(2)` is the shape parameter, `B`.

`[logL,AVAR] = wbllike(params,data)` also returns `AVAR`, which is the asymptotic variance-covariance matrix of the parameter estimates if the values in `params` are the maximum likelihood estimates. `AVAR` is the inverse of Fisher's information matrix. The diagonal elements of `AVAR` are the asymptotic variances of their respective parameters.

`[...] = wbllike(params,data,censoring)` accepts a Boolean vector, `censoring`, of the same size as `data`, which is 1 for observations that are right-censored and 0 for observations that are observed exactly.

`[...] = wbllike(params,data,censoring,freq)` accepts a frequency vector, `freq`, of the same size as `data`. `freq` typically contains integer frequencies for the corresponding elements in `data`, but can contain any nonnegative values. Pass in `[]` for `censoring` to use its default value.

The Weibull negative log-likelihood for uncensored data is

$$(-\log L) = -\log \prod_{i=1}^n f(a,b | x_i) = -\sum_{i=1}^n \log f(a,b | x_i)$$

where f is the Weibull pdf.

`wbllike` is a utility function for maximum likelihood estimation.

Examples This example continues the example from `wblfit`.

```
r = wblrnd(0.5,0.8,100,1);
```

```
[logL, AVAR] = wbllike(wblfit(r),r)
logL =
    47.3349
AVAR =
    0.0048    0.0014
    0.0014    0.0040
```

References

[1] Patel, J. K., C. H. Kapadia, and D. B. Owen. *Handbook of Statistical Distributions*. New York: Marcel Dekker, 1976.

See Also

wblfit | wblpdf | wblcdf | wblinv | wblstat | wblrnd

How To

- “Weibull Distribution” on page B-116

wblpdf

Purpose Weibull probability density function

Syntax `Y = wblpdf(X,A,B)`

Description `Y = wblpdf(X,A,B)` computes the Weibull pdf at each of the values in `X` using the corresponding scale parameter, `A` and shape parameter, `B`. `X`, `A`, and `B` can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other inputs. The parameters in `A` and `B` must be positive.

The Weibull pdf is

$$f(x|a,b) = \frac{b}{a} \left(\frac{x}{a}\right)^{b-1} e^{-(x/a)^b}.$$

Some references refer to the Weibull distribution with a single parameter. This corresponds to `wblpdf` with `A = 1`.

Examples The exponential distribution is a special case of the Weibull distribution.

```
lambda = 1:6;  
y = wblpdf(0.1:0.1:0.6,lambda,1)  
y =  
    0.9048    0.4524    0.3016    0.2262    0.1810    0.1508  
  
y1 = exppdf(0.1:0.1:0.6,lambda)  
y1 =  
    0.9048    0.4524    0.3016    0.2262    0.1810    0.1508
```

References [1] Devroye, L. *Non-Uniform Random Variate Generation*. New York: Springer-Verlag, 1986.

See Also `pdf` | `wblcdf`

How To

- wblfit
- wblinv
- wbllike
- wblplot
- wblrnd
- wblstat
- “Weibull Distribution” on page B-116

wblplot

Purpose Weibull probability plot

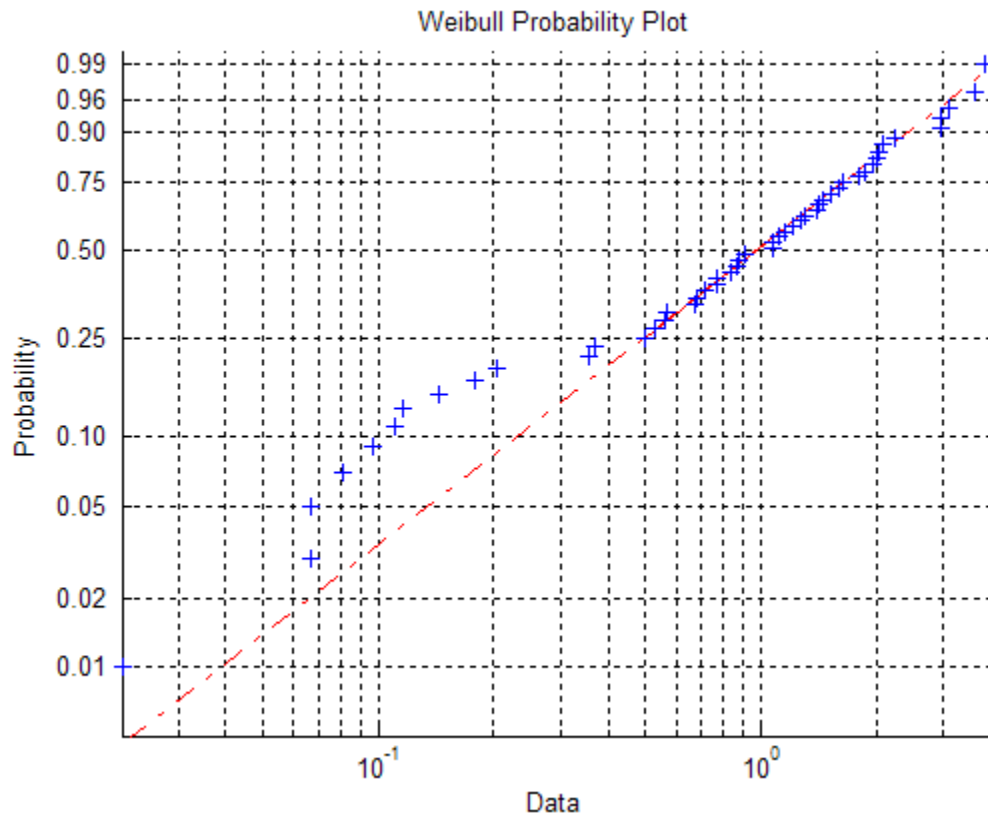
Syntax `wblplot(X)`
`h = wblplot(X)`

Description `wblplot(X)` displays a Weibull probability plot of the data in `X`. If `X` is a matrix, `wblplot` displays a plot for each column.

`h = wblplot(X)` returns handles to the plotted lines.

The purpose of a Weibull probability plot is to graphically assess whether the data in `X` could come from a Weibull distribution. If the data are Weibull the plot will be linear. Other distribution types might introduce curvature in the plot. `wblplot` uses midpoint probability plotting positions. Use `probplot` when the data included censored observations.

Examples `r = wblrnd(1.2,1.5,50,1);`
`wblplot(r)`

**See Also**

`probplot` | `normplot` | `wblcdf`

How To

- `wblfit`
- `wblinv`
- `wbllike`
- `wblpdf`
- `wblrnd`

- wblstat
- “Weibull Distribution” on page B-116

Purpose	Weibull random numbers
Syntax	<pre>R = wblrnd(A,B) R = wblrnd(A,B,m,n,...) R = wblrnd(A,B,[m,n,...])</pre>
Description	<p><code>R = wblrnd(A,B)</code> generates random numbers for the Weibull distribution with scale parameter, <code>A</code> and shape parameter, <code>B</code>. The input arguments <code>A</code> and <code>B</code> can be either scalars or matrices. <code>A</code> and <code>B</code>, can be vectors, matrices, or multidimensional arrays that all have the same size. A scalar input is expanded to a constant array of the same size as the other input.</p> <p><code>R = wblrnd(A,B,m,n,...)</code> or <code>R = wblrnd(A,B,[m,n,...])</code> generates an <code>m</code>-by-<code>n</code>-by-... array. The <code>A</code>, <code>B</code> parameters can each be scalars or arrays of the same size as <code>R</code>.</p> <p>Devroye [1] refers to the Weibull distribution with a single parameter; this is <code>wblrnd</code> with <code>A = 1</code>.</p>
Examples	<pre>n1 = wblrnd(0.5:0.5:2,0.5:0.5:2) n1 = 0.0178 0.0860 2.5216 0.9124 n2 = wblrnd(1/2,1/2,[1 6]) n2 = 0.0046 1.7214 2.2108 0.0367 0.0531 0.0917</pre>
References	[1] Devroye, L. <i>Non-Uniform Random Variate Generation</i> . New York: Springer-Verlag, 1986.
See Also	<code>random</code> <code>wblpdf</code> <code>wblcdf</code> <code>wblinv</code> <code>wblstat</code> <code>wblfit</code> <code>wbllike</code>
How To	• “Weibull Distribution” on page B-116

wblstat

Purpose Weibull mean and variance

Syntax `[M,V] = wblstat(A,B)`

Description `[M,V] = wblstat(A,B)` returns the mean of and variance for the Weibull distribution with scale parameter, *A* and shape parameter, *B*. Vector or matrix inputs for *A* and *B* must have the same size, which is also the size of *M* and *V*. A scalar input for *A* or *B* is expanded to a constant matrix with the same dimensions as the other input.

The mean of the Weibull distribution with parameters *a* and *b* is

$$a \left[\Gamma(1+b^{-1}) \right]$$

and the variance is

$$a^2 \left[\Gamma(1+2b^{-1}) - \Gamma(1+b^{-1})^2 \right]$$

Examples

```
[m,v] = wblstat(1:4,1:4)
m =
    1.0000    1.7725    2.6789    3.6256
v =
    1.0000    0.8584    0.9480    1.0346
```

```
wblstat(0.5,0.7)
ans =
    0.6329
```

See Also

`wblpdf` | `wblcdf` | `wblinv` | `wblfit` | `wbllike` | `wblrnd`

How To

- “Weibull Distribution” on page B-116

Purpose	Wishart random numbers
Syntax	<pre>W = wishrnd(Sigma,df) W = wishrnd(Sigma,df,D) [W,D] = wishrnd(Sigma,df)</pre>
Description	<p><code>W = wishrnd(Sigma,df)</code> generates a random matrix <code>W</code> having the Wishart distribution with covariance matrix <code>Sigma</code> and with <code>df</code> degrees of freedom. The inverse of <code>W</code> has the Inverse Wishart distribution with parameters <code>Tau = inv(Sigma)</code> and <code>df</code> degrees of freedom.</p> <p><code>W = wishrnd(Sigma,df,D)</code> expects <code>D</code> to be the Cholesky factor of <code>Sigma</code>. If you call <code>wishrnd</code> multiple times using the same value of <code>Sigma</code>, it's more efficient to supply <code>D</code> instead of computing it each time.</p> <p><code>[W,D] = wishrnd(Sigma,df)</code> returns <code>D</code> so you can provide it as input in future calls to <code>wishrnd</code>.</p> <p>This function defines the parameter <code>Sigma</code> so that the mean of the output matrix is <code>Sigma*df</code></p>
See Also	<code>iwishrnd</code>
How To	<ul style="list-style-type: none">• “Wishart Distribution” on page B-119

TreeBagger.X property

Purpose X data used to create ensemble

Description The X property is a numeric matrix of size Nobs-by-Nvars, where Nobs is the number of observations (rows) and Nvars is the number of variables (columns) in the training data. This matrix contains the predictor (or feature) values.

Purpose Create dataset array from data stored in SAS XPORT format file

Syntax

```
data = xptread
data = xptread(filename)
[data,missing] = xptread(filename)
xptread(...,'ReadObsNames',true)
```

Description `data = xptread` displays a dialog box for selecting a file, then reads data from the file into a dataset array. The file must be in the SAS XPORT format.

`data = xptread(filename)` retrieves data from a SAS XPORT format file `filename`. The XPORT format allows for 28 missing data types, represented in the file by an upper case letter, '.' or '_'. `xptread` converts All missing data to NaN values in `data`. However, if you need the specific missing types then you can recover this information by specifying a second output.

`[data,missing] = xptread(filename)` returns a nominal array, `missing`, of the same size as `data` containing the missing data type information from the xport format file. The entries are undefined for values that are not present and are one of '.', '_', 'A', ..., 'Z' for missing values.

`xptread(...,'ReadObsNames',true)` treats the first variable in the file as observation names. The default value is false.

`xptread` only supports single data sets per file. `xptread` does not support compressed files.

Examples Read in a SAS XPORT format dataset:

```
data = xptread('sample.xpt')
```

See Also `dataset` | `dataset.export`

Purpose Convert predictor matrix to design matrix

Syntax

```
D = x2fx(X,model)
D = x2fx(X,model,categ)
D = x2fx(X,model,categ,catlevels)
```

Description `D = x2fx(X,model)` converts a matrix of predictors `X` to a design matrix `D` for regression analysis. Distinct predictor variables should appear in different columns of `X`.

The optional input `model` controls the regression model. By default, `x2fx` returns the design matrix for a linear additive model with a constant term. `model` is one of the following strings:

- 'linear' — Constant and linear terms. This is the default.
- 'interaction' — Constant, linear, and interaction terms
- 'quadratic' — Constant, linear, interaction, and squared terms
- 'purequadratic' — Constant, linear, and squared terms

If `X` has n columns, the order of the columns of `D` for a full quadratic model is:

- 1** The constant term
- 2** The linear terms (the columns of `X`, in order 1, 2, ..., n)
- 3** The interaction terms (pairwise products of the columns of `X`, in order (1, 2), (1, 3), ..., (1, n), (2, 3), ..., ($n-1$, n))
- 4** The squared terms (in order 1, 2, ..., n)

Other models use a subset of these terms, in the same order.

Alternatively, `model` can be a matrix specifying polynomial terms of arbitrary order. In this case, `model` should have one column for each column in `X` and one row for each term in the model. The entries in any row of `model` are powers for the corresponding columns of `X`. For example, if `X` has columns `X1`, `X2`, and `X3`, then a row `[0 1 2]` in `model`

specifies the term $(X1.^0) \cdot (X2.^1) \cdot (X3.^2)$. A row of all zeros in *model* specifies a constant term, which can be omitted.

`D = x2fx(X,model,categ)` treats columns with numbers listed in the vector *categ* as categorical variables. Terms involving categorical variables produce dummy variable columns in *D*. Dummy variables are computed under the assumption that possible categorical levels are completely enumerated by the unique values that appear in the corresponding column of *X*.

`D = x2fx(X,model,categ,catlevels)` accepts a vector *catlevels* the same length as *categ*, specifying the number of levels in each categorical variable. In this case, values in the corresponding column of *X* must be integers in the range from 1 to the specified number of levels. Not all of the levels need to appear in *X*.

Examples

Example 1

The following converts 2 predictors *X1* and *X2* (the columns of *X*) into a design matrix for a full quadratic model with terms constant, *X1*, *X2*, $X1 \cdot X2$, $X1.^2$, and $X2.^2$.

```
X = [1 10
     2 20
     3 10
     4 20
     5 15
     6 15];
```

```
D = x2fx(X,'quadratic')
D =
     1     1    10    10     1    100
     1     2    20    40     4    400
     1     3    10    30     9    100
     1     4    20    80    16    400
     1     5    15    75    25    225
     1     6    15    90    36    225
```

Example 2

The following converts 2 predictors X1 and X2 (the columns of X) into a design matrix for a quadratic model with terms constant, X1, X2, X1.*X2, and X1.^2.

```
X = [1 10
      2 20
      3 10
      4 20
      5 15
      6 15];
model = [0 0
         1 0
         0 1
         1 1
         2 0];

D = x2fx(X,model)
D =
     1     1    10    10     1
     1     2    20    40     4
     1     3    10    30     9
     1     4    20    80    16
     1     5    15    75    25
     1     6    15    90    36
```

See Also

[regstats](#) | [rstool](#) | [candexch](#) | [candgen](#) | [cordexch](#) | [rowexch](#)

Purpose Y data used to create ensemble

Description The Y property is an array of true class labels for classification, or response values for regression. Y can be a numeric column vector, a character matrix, or a cell array of strings.

zscore

Purpose Standardized z -scores

Syntax

```
Z = zscore(X)
Z = zscore(X, flag)
Z = zscore(X, flag, dim)
[Z, mu, sigma] = zscore( ___ )
```

Description `Z = zscore(X)` returns the z -score for each element of X such that columns of X are centered to have mean 0 and scaled to have standard deviation 1. Z is the same size as X .

- If X is a vector, then Z is a vector of z -scores.
- If X is a matrix, then Z is a matrix of the same size as X , and each column of Z has mean 0 and standard deviation 1.
- For multidimensional arrays, z -scores in Z are computed along the first nonsingleton dimension of X .

`Z = zscore(X, flag)` scales X using the standard deviation indicated by `flag`.

- If `flag` is 0 (default), then `zscore` scales X using the sample standard deviation, with $n - 1$ in the denominator of the standard deviation formula. `zscore(X, 0)` is the same as `zscore(X)`.
- If `flag` is 1, then `zscore` scales X using the population standard deviation, with n in the denominator of standard deviation formula.

`Z = zscore(X, flag, dim)` standardizes X along dimension `dim`. For example, for a matrix X , if `dim = 1`, then `zscore` uses the means and standard deviations along the columns of X , if `dim = 2`, then `zscore` uses the means and standard deviations along the rows of X .

`[Z, mu, sigma] = zscore(___)` also returns the means and standard deviations used for centering and scaling, `mu` and `sigma`, respectively. You can use any of the input arguments in the previous syntaxes.

Input Arguments

X - Input data

vector | matrix | multidimensional array

Input data, specified as a vector, matrix, or multidimensional array.

Data Types

double | single

flag - Indicator for the standard deviation

0 (default) | 1

Indicator for the standard deviation used to compute the z -scores, specified as 0 or 1.

- If `flag` is 0 (default), then `zscore` scales X using the sample standard deviation. `zscore(X,0)` is the same as `zscore(X)`.
- If `flag` is 1, then `zscore` scales X using the population standard deviation.

dim - Dimension

1 (default) | positive integer

Dimension along which to calculate the z -scores of X , specified as a positive integer. For example, for a matrix X , if `dim` = 1, then `zscore` uses the means and standard deviations along the columns of X , if `dim` = 2, then `zscore` uses the means and standard deviations along the rows of X .

Output Arguments

Z - z-scores

vector | matrix | multidimensional array

z -scores, returned as a vector, matrix, or multidimensional array. A vector of z -scores has mean 0 and variance 1.

- If X is a vector, then Z is a vector of z -scores.
- If X is an array, then `zscore` is an array, with each column or row standardized to have mean 0 and variance 1 (depending on `dim`). If `dim` is not specified, `zscore` standardizes along the first nonsingleton dimension of X .

mu - Mean

scalar | vector

Mean of X used to compute the z -scores, returned as a scalar or vector.

- If X is a vector, then μ is a scalar.
- If X is a matrix, then μ is a row vector if `zscore` calculates the means along the columns of X ($\text{dim} = 1$), and a column vector if `zscore` calculates the means along the rows of X ($\text{dim} = 2$).

sigma - Standard deviation

scalar | vector

Standard deviation of X used to compute the z -scores, returned as a scalar or vector.

- If X is a vector, then σ is a scalar.
- If X is a matrix, then σ is a row vector if `zscore` calculates the standard deviations along the columns of X ($\text{dim} = 1$), and a column vector if `zscore` calculates the standard deviations along the rows of X ($\text{dim} = 2$).

Examples

Z-Scores of Two Data Vectors

Compute and plot the z -scores of two data vectors, and then compare the results.

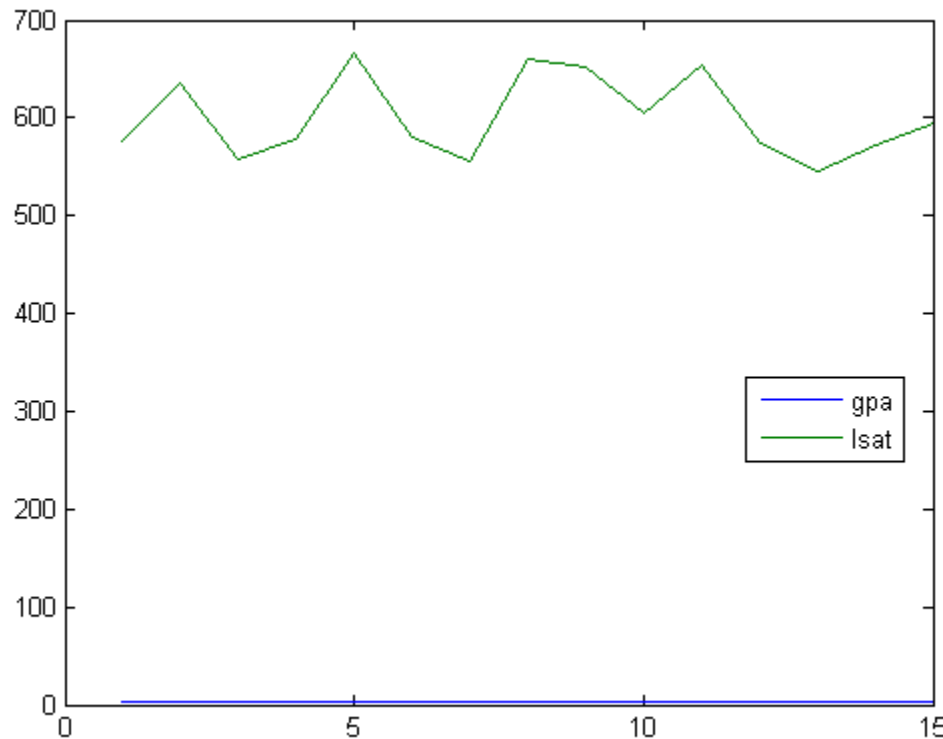
Load the sample data.

```
load('lawdata.mat')
```

Two variables load into the workspace: `gpa` and `lsat`.

Plot both variables on the same axes.

```
plot([gpa,lsat])  
legend('gpa','lsat','Location','East')
```

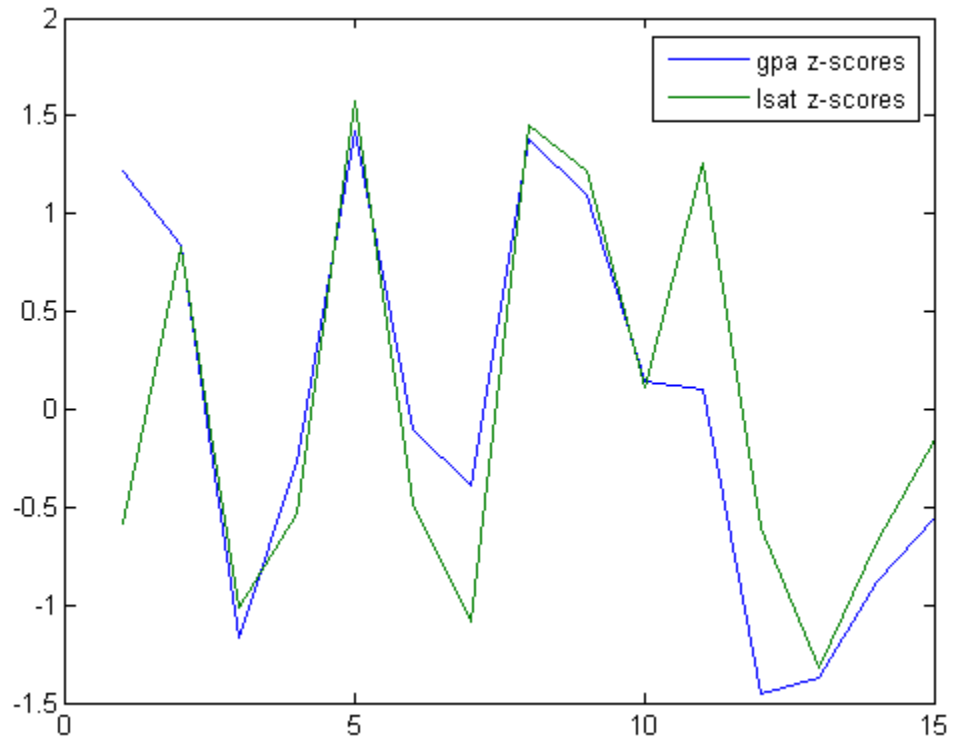



It is difficult to compare these two measures because they are on a very different scale.

Plot the z-scores of gpa and lsat on the same axes.

```
Zgpa = zscore(gpa);  
Zlsat = zscore(lsat);  
plot([Zgpa, Zlsat])  
legend('gpa z-scores', 'lsat z-scores', 'Location', 'Northeast')
```

zscore



Now, you can see the relative performance of individuals with respect to both their `gpa` and `lsat` results. For example, the third individual's `gpa` and `lsat` results are both one standard deviation below the sample mean. The eleventh individual's `gpa` is around the sample mean but has an `lsat` score almost 1.25 standard deviations above the sample average.

Check the mean and standard deviation of the `z`-scores you created.

```
mean([Zgpa,Zlsat])
```

```
ans =  
  
1.0e-14 *  
-0.1088    0.0357  
  
std([Zgpa,Zlsat])
```

```
ans =  
  
1    1
```

By definition, z -scores of gpa and lsat have mean 0 and standard deviation 1.

Z-Scores for a Population vs. Sample

Load the sample data.

```
load('lawdata.mat')
```

Two variables load into the workspace: gpa and lsat.

Compute the z -scores of gpa using the population formula for standard deviation.

```
Z1 = zscore(gpa,1); % population formula  
Z0 = zscore(gpa,0); % sample formula  
disp([Z1 Z0])
```

```
1.2554    1.2128  
0.8728    0.8432  
-1.2100   -1.1690  
-0.2749   -0.2656  
1.4679    1.4181  
-0.1049   -0.1013  
-0.4024   -0.3888  
1.4254    1.3771  
1.1279    1.0896
```

```
0.1502    0.1451
0.1077    0.1040
-1.5076   -1.4565
-1.4226   -1.3743
-0.9125   -0.8815
-0.5724   -0.5530
```

For a sample from a population, the population standard deviation formula with n in the denominator corresponds to the maximum likelihood estimate of the population standard deviation, and might be biased. The sample standard deviation formula, on the other hand, is the unbiased estimator of the population standard deviation for a sample.

Z-Scores of a Data Matrix

Compute z -scores using the mean and standard deviation computed along the columns or rows of a data matrix.

Load the sample data.

```
load('flu.mat')
```

The dataset array `flu` is loaded in the workplace. `flu` has 52 observations on 11 variables. The first variable contains dates (in weeks). The other variables contain the flu estimates for different regions in the U.S.

Convert the dataset array to a data matrix.

```
flu2 = double(flu(:,2:end));
```

The new data matrix, `flu2`, is a 52-by-10 double data matrix. The rows correspond to the weeks and the columns correspond to the U.S. regions in the data set array `flu`.

Standardize the flu estimate for each region (the *columns* of `flu2`).

```
Z1 = zscore(flu2,[ ],1);
```

You can see the z -scores in the variable editor by double-clicking on the matrix `Z1` created in the workspace.

Standardize the flu estimate for each week (the *rows* of `flu2`).

```
Z2 = zscore(flu2,[ ],2);
```

Z-Scores, Mean, and Standard Deviation

Return the mean and standard deviation used to compute the z -scores.

Load the sample data.

```
load('lawdata.mat')
```

Two variables load into the workspace: `gpa` and `lsat`.

Return the z -scores, mean, and standard deviation of `gpa`.

```
[Z,gpamean,gpastdev] = zscore(gpa)
```

```
Z =
```

```
    1.2128  
    0.8432  
   -1.1690  
   -0.2656  
    1.4181  
   -0.1013  
   -0.3888  
    1.3771  
    1.0896  
    0.1451  
    0.1040  
   -1.4565  
   -1.3743  
   -0.8815  
   -0.5530
```

gpamean =

3.0947

gpastdev =

0.2435

Definitions

Z-Score

For a random variable X with mean μ and standard deviation σ , the z -score of a value x is

$$z = \frac{(x - \mu)}{\sigma}.$$

For sample data with mean \bar{X} and standard deviation S , the z -score of a data point x is

$$z = \frac{(x - \bar{X})}{S}.$$

z -scores measure the distance of a data point from the mean in terms of the standard deviation. This is also called *standardization* of data. The standardized data set has mean 0 and standard deviation 1, and retains the shape properties of the original data set (same skewness and kurtosis).

You can use z -scores to put data on the same scale before further analysis. This lets you to compare two or more data sets with different units.

Multidimensional Array

A *multidimensional array* is an array with more than two dimensions. For example, if X is a 1-by-3-by-4 array, then X is a three-dimensional array.

First Nonsingleton Dimension

A *first nonsingleton dimension* is the first dimension of an array whose size is not equal to 1. For example, if X is a 1-by-2-by-3-by-4 array, then the second dimension is the first nonsingleton dimension of X .

Sample Standard Deviation

The *sample standard deviation*, S , is given by

$$S = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{X})^2}{n - 1}}.$$

S is the square root of an unbiased estimator of the variance of the population from which X is drawn, as long as X consists of independent, identically distributed samples.

Notice that the denominator in this variance formula is $n - 1$.

Population Standard Deviation

If the data is the entire population of values, then you can use the *population standard deviation*,

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \mu)^2}{n}}.$$

If X is a random sample from a population, then μ is estimated by the sample mean, and σ is the biased maximum likelihood estimator of the population standard deviation.

Notice that the denominator in this variance formula is n .

Algorithms

`zscore` returns NaNs for any sample containing NaNs.

`zscore` returns 0s for any sample that is constant (all values are the same). For example, if X is a vector of the same numeric value, then Z is a vector of 0s. If X is a matrix with a column of consisting of the same value, then that column of Z consists of 0s.

zscore

See Also

[mean](#) | [std](#)

Purpose

`z-test`

Syntax

```
h = ztest(x,m,sigma)
h = ztest(...,alpha)
h = ztest(...,alpha,tail)
h = ztest(...,alpha,tail,dim)
[h,p] = ztest(...)
[h,p,ci] = ztest(...)
[h,p,ci,zval] = ztest(...)
```

Description

`h = ztest(x,m,sigma)` performs a *z*-test of the null hypothesis that data in the vector `x` are a random sample from a normal distribution with mean `m` and standard deviation `sigma`, against the alternative that the mean is not `m`. The result of the test is returned in `h`. `h = 1` indicates a rejection of the null hypothesis at the 5% significance level. `h = 0` indicates a failure to reject the null hypothesis at the 5% significance level.

`x` can also be a matrix or an *N*-dimensional array. For matrices, `ztest` performs separate *z*-tests along each column of `x` and returns a vector of results. For *N*-dimensional arrays, `ztest` works along the first non-singleton dimension of `x`.

The test treats NaN values as missing data, and ignores them.

`h = ztest(...,alpha)` performs the test at the $(100*\alpha)\%$ significance level. The default, when unspecified, is `alpha = 0.05`.

`h = ztest(...,alpha,tail)` performs the test against the alternative specified by the string `tail`. There are three options for `tail`:

- `'both'` — Mean is not `m` (two-tailed test). This is the default, when `tail` is unspecified.
- `'right'` — Mean is greater than `m` (right-tail test)
- `'left'` — Mean is less than `m` (left-tail test)

`tail` must be a single string, even when `x` is a matrix or an *N*-dimensional array.

`h = ztest(...,alpha,tail,dim)` works along dimension `dim` of `x`. Use `[]` to pass in default values for `alpha` or `tail`.

`[h,p] = ztest(...)` returns the p value of the test. The p value is the probability, under the null hypothesis, of observing a value as extreme or more extreme of the test statistic

$$z = \frac{\bar{x} - \mu}{\sigma / \sqrt{n}}$$

where \bar{x} is the sample mean, $\mu = m$ is the hypothesized population mean, σ is the population standard deviation, and n is the sample size. Under the null hypothesis, the test statistic will have a standard normal distribution, $N(0,1)$.

`[h,p,ci] = ztest(...)` returns a $100*(1 - \text{alpha})\%$ confidence interval on the population mean.

`[h,p,ci,zval] = ztest(...)` returns the value of the test statistic.

Examples

Simulate a random sample of size 100 from a normal distribution with mean 0.1 and standard deviation 1:

```
x = normrnd(0.1,1,1,100);
```

Test the null hypothesis that the sample comes from a standard normal distribution:

```
[h,p,ci] = ztest(x,0,1)
h =
    0
p =
    0.1391
ci =
   -0.0481    0.3439
```

The test fails to reject the null hypothesis at the default $\alpha = 0.05$ significance level. Under the null hypothesis, the probability of observing a value as extreme or more extreme of the test statistic, as

indicated by the p value, is greater than α . The 95% confidence interval on the mean contains 0.

Simulate a larger random sample of size 1000 from the same distribution:

```
y = normrnd(0.1,1,1,1000);
```

Test again if the sample comes from a normal distribution with mean 0:

```
[h,p,ci] = ztest(y,0,1)
h =
     1
p =
 5.5160e-005
ci =
 0.0655    0.1895
```

This time the test rejects the null hypothesis at the default $\alpha = 0.05$ significance level. The p value has fallen below $\alpha = 0.05$ and the 95% confidence interval on the mean does not contain 0.

Because the p value of the sample y is less than 0.01, the test will still reject the null hypothesis when the significance level is lowered to $\alpha = 0.01$:

```
[h,p,ci] = ztest(y,0,1,0.01)
h =
     1
p =
 5.5160e-005
ci =
 0.0461    0.2090
```

This example will produce slightly different results each time it is run, because of the random sampling.

See Also

ttest | ttest2

Sample Data Sets

Statistics Toolbox software includes the sample data sets in the following table.

To load a data set into the MATLAB workspace, type:

```
load filename
```

where *filename* is one of the files listed in the table.

Data sets contain individual data variables, description variables with references, and dataset arrays encapsulating the data set and its description, as appropriate.

File	Description of Data Set
acetylene.mat	Chemical reaction data with correlated predictors
arrhythmia.mat	Cardiac arrhythmia data from the UCI machine learning repository
carbig.mat	Measurements of cars, 1970–1982
carsmall.mat	Subset of carbig.mat. Measurements of cars, 1970, 1976, 1982
cereal.mat	Breakfast cereal ingredients
cities.mat	Quality of life ratings for U.S. metropolitan areas
discrim.mat	A version of cities.mat used for discriminant analysis
examgrades.mat	Exam grades on a scale of 0–100
fisheriris.mat	Fisher’s 1936 iris data
flu.mat	Google Flu Trends estimated ILI (influenza-like illness) percentage for various regions of the US, and CDC weighted ILI percentage based on sentinel provider reports
gas.mat	Gasoline prices around the state of Massachusetts in 1993
hald.mat	Heat of cement vs. mix of ingredients
hogg.mat	Bacteria counts in different shipments of milk

File	Description of Data Set
hospital.mat	Simulated hospital data
imports-85.mat	1985 Auto Imports Database from the UCI repository
ionosphere.mat	Ionosphere dataset from the UCI machine learning repository
kmeansdata.mat	Four-dimensional clustered data
lawdata.mat	Grade point average and LSAT scores from 15 law schools
mileage.mat	Mileage data for three car models from two factories
moore.mat	Biochemical oxygen demand on five predictors
morse.mat	Recognition of Morse code distinctions by non-coders
ovariancancer.mat	Grouped observations on 4000 predictors
parts.mat	Dimensional run-out on 36 circular parts
polydata.mat	Sample data for polynomial fitting
popcorn.mat	Popcorn yield by popper type and brand
reaction.mat	Reaction kinetics for Hougen-Watson model
sat.dat	Scholastic Aptitude Test averages by gender and test (table)
sat2.dat	Scholastic Aptitude Test averages by gender and test (csv)
spectra.mat	NIR spectra and octane numbers of 60 gasoline samples
stockreturns.mat	Simulated stock returns

Distribution Reference

- “Bernoulli Distribution” on page B-3
- “Beta Distribution” on page B-4
- “Binomial Distribution” on page B-7
- “Birnbaum-Saunders Distribution” on page B-10
- “Burr Type XII Distribution” on page B-12
- “Chi-Square Distribution” on page B-25
- “Copulas” on page B-27
- “Custom Distributions” on page B-28
- “Exponential Distribution” on page B-29
- “Extreme Value Distribution” on page B-32
- “F Distribution” on page B-38
- “Gamma Distribution” on page B-40
- “Gaussian Distribution” on page B-43
- “Gaussian Mixture Distributions” on page B-44
- “Generalized Extreme Value Distribution” on page B-45
- “Generalized Pareto Distribution” on page B-50
- “Geometric Distribution” on page B-54
- “Hypergeometric Distribution” on page B-56
- “Inverse Gaussian Distribution” on page B-58
- “Inverse Wishart Distribution” on page B-59
- “Johnson System” on page B-61

- “Logistic Distribution” on page B-62
- “Loglogistic Distribution” on page B-63
- “Lognormal Distribution” on page B-64
- “Multinomial Distribution” on page B-67
- “Multivariate Gaussian Distribution” on page B-70
- “Multivariate Normal Distribution” on page B-71
- “Multivariate t Distribution” on page B-77
- “Nakagami Distribution” on page B-83
- “Negative Binomial Distribution” on page B-85
- “Noncentral Chi-Square Distribution” on page B-89
- “Noncentral F Distribution” on page B-91
- “Noncentral t Distribution” on page B-93
- “Nonparametric Distributions” on page B-95
- “Normal Distribution” on page B-96
- “Pareto Distribution” on page B-99
- “Pearson System” on page B-100
- “Piecewise Distributions” on page B-101
- “Poisson Distribution” on page B-102
- “Rayleigh Distribution” on page B-104
- “Rician Distribution” on page B-106
- “Student’s t Distribution” on page B-108
- “t Location-Scale Distribution” on page B-110
- “Uniform Distribution (Continuous)” on page B-112
- “Uniform Distribution (Discrete)” on page B-114
- “Weibull Distribution” on page B-116
- “Wishart Distribution” on page B-119

Bernoulli Distribution

Definition of the Bernoulli Distribution

The Bernoulli distribution is a special case of the binomial distribution, with $n = 1$.

See Also

“Discrete Distributions” on page 5-8

Beta Distribution

In this section...
“Definition” on page B-4
“Background” on page B-4
“Parameters” on page B-5
“Example” on page B-6
“See Also” on page B-6

Definition

The beta pdf is

$$y = f(x | a, b) = \frac{1}{B(a, b)} x^{a-1} (1-x)^{b-1} I_{(0,1)}(x)$$

where $B(\cdot)$ is the Beta function. The indicator function $I_{(0,1)}(x)$ ensures that only values of x in the range $(0, 1)$ have nonzero probability.

Background

The beta distribution describes a family of curves that are unique in that they are nonzero only on the interval $(0, 1)$. A more general version of the function assigns parameters to the endpoints of the interval.

The beta cdf is the same as the incomplete beta function.

The beta distribution has a functional relationship with the t distribution. If Y is an observation from Student’s t distribution with ν degrees of freedom, then the following transformation generates X , which is beta distributed.

$$X = \frac{1}{2} + \frac{1}{2} \frac{Y}{\sqrt{\nu + Y^2}}$$

If $Y \sim t(v)$, then $X \sim \beta\left(\frac{v}{2}, \frac{v}{2}\right)$

This relationship is used to compute values of the t cdf and inverse function as well as generating t distributed random numbers.

Parameters

Suppose you are collecting data that has hard lower and upper bounds of zero and one respectively. Parameter estimation is the process of determining the parameters of the beta distribution that fit this data best in some sense.

One popular criterion of goodness is to maximize the likelihood function. The likelihood has the same form as the beta pdf. But for the pdf, the parameters are known constants and the variable is x . The likelihood function reverses the roles of the variables. Here, the sample values (the x 's) are already observed. So they are the fixed constants. The variables are the unknown parameters. Maximum likelihood estimation (MLE) involves calculating the values of the parameters that give the highest likelihood given the particular set of data.

The function `betafit` returns the MLEs and confidence intervals for the parameters of the beta distribution. Here is an example using random numbers from the beta distribution with $a = 5$ and $b = 0.2$.

```
r = betarnd(5,0.2,100,1);
[phat, pci] = betafit(r)
```

```
phat =
    4.5330    0.2301
```

```
pci =
    2.8051    0.1771
    6.2610    0.2832
```

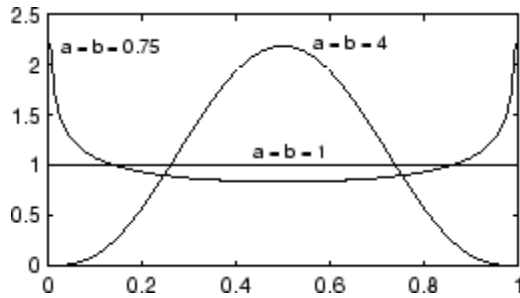
The MLE for parameter a is 4.5330, compared to the true value of 5. The 95% confidence interval for a goes from 2.8051 to 6.2610, which includes the true value.

Similarly the MLE for parameter b is 0.2301, compared to the true value of 0.2. The 95% confidence interval for b goes from 0.1771 to 0.2832, which

also includes the true value. In this made-up example you know the “true value.” In experimentation you do not.

Example

The shape of the beta distribution is quite variable depending on the values of the parameters, as illustrated by the plot below.



The constant pdf (the flat line) shows that the standard uniform distribution is a special case of the beta distribution.

See Also

“Continuous Distributions (Data)” on page 5-4

Binomial Distribution

In this section...

“Definition” on page B-7
“Background” on page B-7
“Parameters” on page B-8
“Example” on page B-9
“See Also” on page B-9

Definition

The binomial pdf is

$$f(k | n, p) = \binom{n}{k} p^k (1-p)^{n-k}$$

where k is the number of successes in n trials of a Bernoulli process with probability of success p .

The binomial distribution is discrete, defined for integers $k = 0, 1, 2, \dots, n$, where it is nonzero.

Background

The binomial distribution models the total number of successes in repeated trials from an infinite population under the following conditions:

- Only two outcomes are possible on each of n trials.
- The probability of success for each trial is constant.
- All trials are independent of each other.

The binomial distribution is a generalization of the Bernoulli distribution; it generalizes to the multinomial distribution.

Parameters

Suppose you are collecting data from a widget manufacturing process, and you record the number of widgets within specification in each batch of 100. You might be interested in the probability that an individual widget is within specification. Parameter estimation is the process of determining the parameter, p , of the binomial distribution that fits this data best in some sense.

One popular criterion of goodness is to maximize the likelihood function. The likelihood has the same form as the binomial pdf above. But for the pdf, the parameters (n and p) are known constants and the variable is x . The likelihood function reverses the roles of the variables. Here, the sample values (the x 's) are already observed. So they are the fixed constants. The variables are the unknown parameters. MLE involves calculating the value of p that give the highest likelihood given the particular set of data.

The function `binofit` returns the MLEs and confidence intervals for the parameters of the binomial distribution. Here is an example using random numbers from the binomial distribution with $n = 100$ and $p = 0.9$.

```
r = binornd(100,0.9)

r =
    88

[phat, pci] = binofit(r,100)

phat =
    0.8800

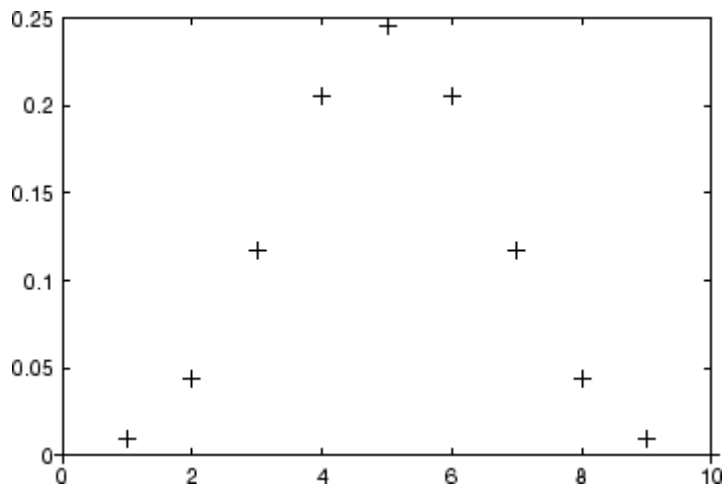
pci =
    0.7998
    0.9364
```

The MLE for parameter p is 0.8800, compared to the true value of 0.9. The 95% confidence interval for p goes from 0.7998 to 0.9364, which includes the true value. In this made-up example you know the “true value” of p . In experimentation you do not.

Example

The following commands generate a plot of the binomial pdf for $n = 10$ and $p = 1/2$.

```
x = 0:10;  
y = binopdf(x,10,0.5);  
plot(x,y,'+')
```



See Also

“Discrete Distributions” on page 5-8

Birnbaum-Saunders Distribution

In this section...

“Definition” on page B-10

“Background” on page B-10

“Parameters” on page B-11

“See Also” on page B-11

Definition

The Birnbaum-Saunders distribution has the density function

$$\frac{1}{\sqrt{2\pi}} \exp \left\{ - \frac{\left(\sqrt{x/\beta} - \sqrt{\beta/x} \right)^2}{2\gamma^2} \right\} \left(\frac{\sqrt{x/\beta} + \sqrt{\beta/x}}{2\gamma x} \right)$$

with scale parameter $\beta > 0$ and shape parameter $\gamma > 0$, for $x > 0$.

If x has a Birnbaum-Saunders distribution with parameters β and γ , then

$$\frac{\left(\sqrt{x/\beta} - \sqrt{\beta/x} \right)}{\gamma}$$

has a standard normal distribution.

Background

The Birnbaum-Saunders distribution was originally proposed as a lifetime model for materials subject to cyclic patterns of stress and strain, where the ultimate failure of the material comes from the growth of a prominent flaw. In materials science, Miner’s Rule suggests that the damage occurring after n cycles, at a stress level with an expected lifetime of N cycles, is proportional

to n / N . Whenever Miner's Rule applies, the Birnbaum-Saunders model is a reasonable choice for a lifetime distribution model.

Parameters

See `mle`, `dfittool`.

See Also

"Continuous Distributions (Data)" on page 5-4

Burr Type XII Distribution

In this section...
“Definition” on page B-12
“Background” on page B-13
“Parameters” on page B-14
“Fit a Burr Distribution and Draw the cdf” on page B-15
“Compare Lognormal and Burr pdfs” on page B-17
“Burr pdf for Various Parameters” on page B-19
“Survival and Hazard Functions of Burr Distribution” on page B-20
“Divergence of Parameter Estimates” on page B-22
“See Also” on page B-24

Definition

The Burr type XII distribution is a three-parameter family of distributions on the positive real line. The cumulative distribution function (cdf) of the Burr distribution is

$$F(x | \alpha, c, k) = 1 - \frac{1}{\left(1 + \left(\frac{x}{\alpha}\right)^c\right)^k}, \quad x > 0, \alpha > 0, c > 0, k > 0,$$

where c and k are the shape parameters and α is the scale parameter. The probability density function (pdf) is

$$f(x | \alpha, c, k) = \frac{\frac{kc}{\alpha} \left(\frac{x}{\alpha}\right)^{c-1}}{\left(1 + \left(\frac{x}{\alpha}\right)^c\right)^{k+1}}, \quad x > 0, \alpha > 0, c > 0, k > 0.$$

The density of the Burr type XII distribution is L-shaped if $c \leq 1$ and unimodal, otherwise.

Background

Burr distribution was first discussed by Burr (1942) as a two-parameter family. An additional scale parameter was introduced by Tadikamalla (1980). It is a very flexible distribution family that can express a wide range of distribution shapes. The Burr distribution includes, overlaps, or has as a limiting case, many commonly used distributions such as gamma, lognormal, loglogistic, bell-shaped, and J-shaped beta distributions (but not U-shaped). Some compound distributions also correspond to the Burr distribution. For example, compounding a Weibull distribution with a gamma distribution for its scale parameter results in a Burr distribution. Similarly, compounding an exponential distribution with a gamma distribution for its rate parameter, $1/\mu$, also yields a Burr distribution. The Burr distribution also has two asymptotic limiting cases: Weibull and Pareto Type I.

The Burr distribution can fit a wide range of empirical data. Different values of its parameters cover a broad set of skewness and kurtosis. Hence, it is used in various fields such as finance, hydrology, and reliability to model a variety of data types. Examples of data modeled by the Burr distribution are household income, crop prices, insurance risk, travel time, flood levels, and failure data.

The survival and hazard functions of Burr type XII distribution are, respectively,

$$S(x | \alpha, c, k) = \frac{1}{\left[1 + \left(\frac{x}{\alpha}\right)^c\right]^k}$$

and

$$h(x | \alpha, c, k) = \frac{\frac{kc}{\alpha} \left(\frac{x}{\alpha}\right)^{c-1}}{1 + \left(\frac{x}{\alpha}\right)^c}.$$

If $c > 1$, the hazard function $h(x)$ is non-monotonic with a mode at $x = \alpha(c - 1)^{1/c}$.

Parameters

The three-parameter Burr distribution is defined by its scale parameter α and shape parameters c and k . You can estimate the parameters using `mle` or `fitdist`. Both functions support censored data for Burr distribution.

Generate sample data from a Burr distribution with scale parameter 0.5 and shape parameters 2 and 5.

```
rng('default')
R = random('burr',0.5,2,5,1000,1);
```

Estimate the parameters and the confidence intervals.

```
[phat,pci] = mle(R,'distribution','burr')
```

```
phat =
```

```
    0.4154    2.1217    4.0550
```

```
pci =
```

```
    0.2985    1.9560    2.4079
    0.5782    2.3014    6.8288
```

The default 95% confidence intervals for the parameters include the true parameter values.

The three-parameter Burr distribution converges asymptotically to one of the two limiting forms as its parameters diverge:

- If $k \rightarrow 0$, $c \rightarrow \infty$, $ck = \lambda$, then the Burr distribution reduces to a two-parameter Pareto distribution with the cdf

$$F_P = 1 - \left(\frac{x}{\alpha}\right)^{-\lambda}, \quad x \geq \alpha.$$

- If $k \rightarrow \infty$, $\alpha \rightarrow \infty$, $\alpha/k^{1/c} = \theta$, then the Burr distribution reduces to a two-parameter Weibull distribution with the cdf

$$F_W(x | c, \theta) = 1 - \exp\left[\left(\frac{x}{\alpha}\right)^{-c}\right].$$

If `mle` or `fitdist` detects such divergence, it returns an error message, but informs you of the limiting distribution and corresponding parameter estimates for that distribution.

Fit a Burr Distribution and Draw the cdf

This example shows how to fit a Burr distribution to data, draw the cdf, and construct a histogram with a Burr distribution fit.

1. Load the sample data.

```
load('arrhythmia.mat')
```

The fifth column in `X` contains a measurement obtained from electrocardiograms, called QRS duration.

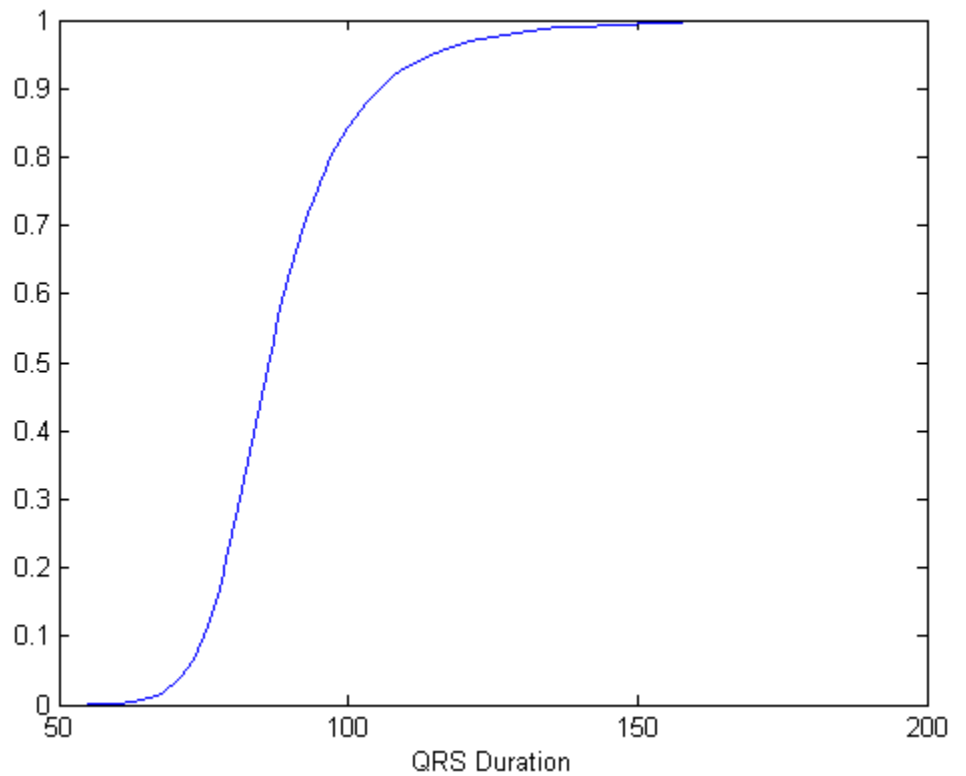
2. Fit a Burr distribution to the QRS duration data, and get the parameter estimates.

```
PD = fitdist(X(:,5), 'burr');
```

`PD` has the maximum likelihood estimates of the Burr distribution parameters in the property `Param`. The estimates are $\alpha = 80.4515$, $c = 18.9251$, $k = 0.4492$.

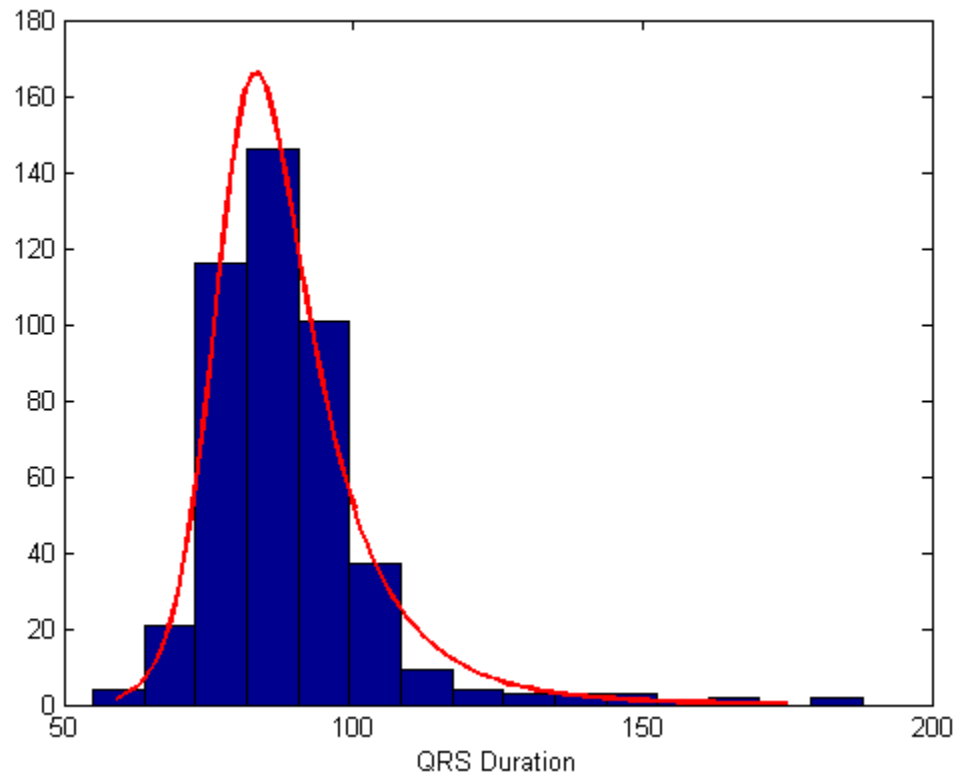
3. Plot the cdf of the QRS duration data.

```
QRScdf=cdf('burr', sortrows(X(:,5)), 80.4515, 18.9251, 0.4492);
plot(sortrows(X(:,5)), QRScdf)
xlabel('QRS Duration')
```

**cdf of QRS duration data**

4. Draw the histogram of QRS duration data with 15 bins and the pdf of the Burr distribution fit.

```
histfit(X(:,5),15,'burr')  
xlabel('QRS Duration')
```

Histogram of QRS data with a Burr distribution fit

Compare Lognormal and Burr pdfs

This example compares the lognormal pdf to the Burr pdf using income data generated from a lognormal distribution.

1. Generate the income data.

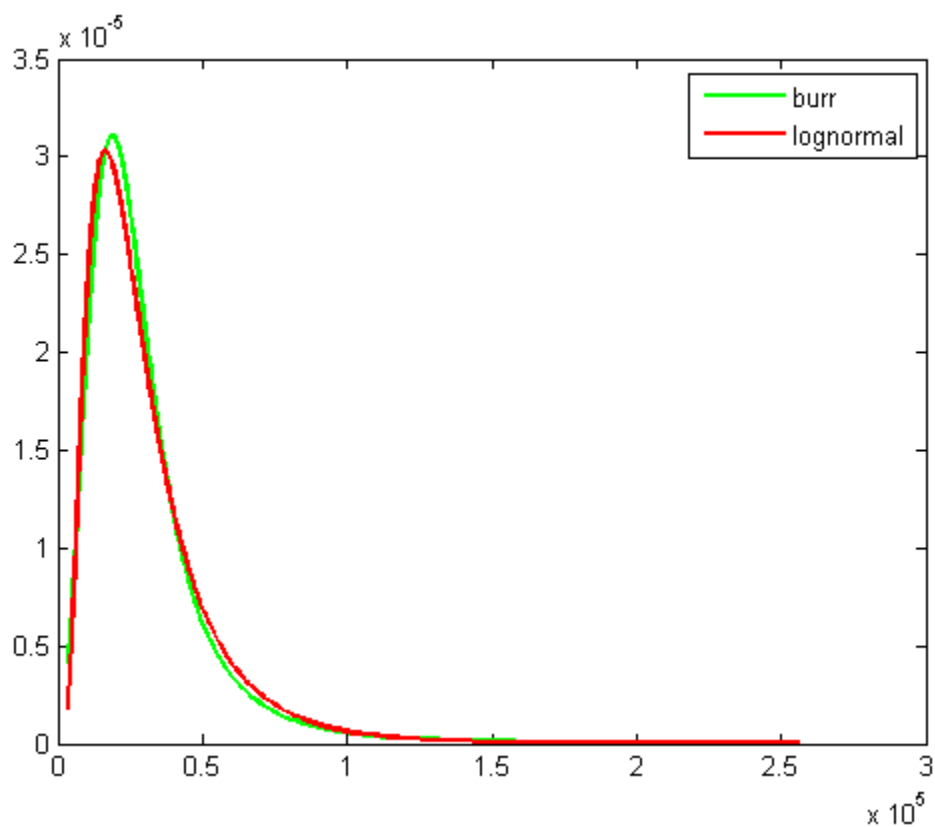
```
rng('default') % for reproducibility
y = random('logn',log(25000),0.65,500,1);
```

2. Fit a Burr distribution.

```
pd = fitdist(y,'burr');
```

3. Plot both the Burr and lognormal pdfs of income data on the same axis.

```
p = pdf('burr',sortrows(y),26007,2.6374,1.0966);  
p2 = pdf('logn',sortrows(y),log(25000),0.65);  
plot(sortrows(y),p,'g',sortrows(y),p2,'r','LineWidth',2)  
legend('burr','lognormal')
```



Burr and Lognormal pdfs fitted to income data

Burr pdf for Various Parameters

This example shows how to create a variety of shapes for probability density functions of the Burr distribution.

```
X = 0:0.01:5;
c = [0.5 0.95 2 5];
k = [0.5 0.75 2 5];
alpha = [0.5 1 2 5];
colors = ['b';'g';'r';'k']

figure
for i = 1:1:4
pdf1(i,:) = pdf('burr',X,1,c(i),0.5);
pdf2(i,:) = pdf('burr',X,1,2,k(i));
pdf3(i,:) = pdf('burr',X,alpha(i),2,0.5);

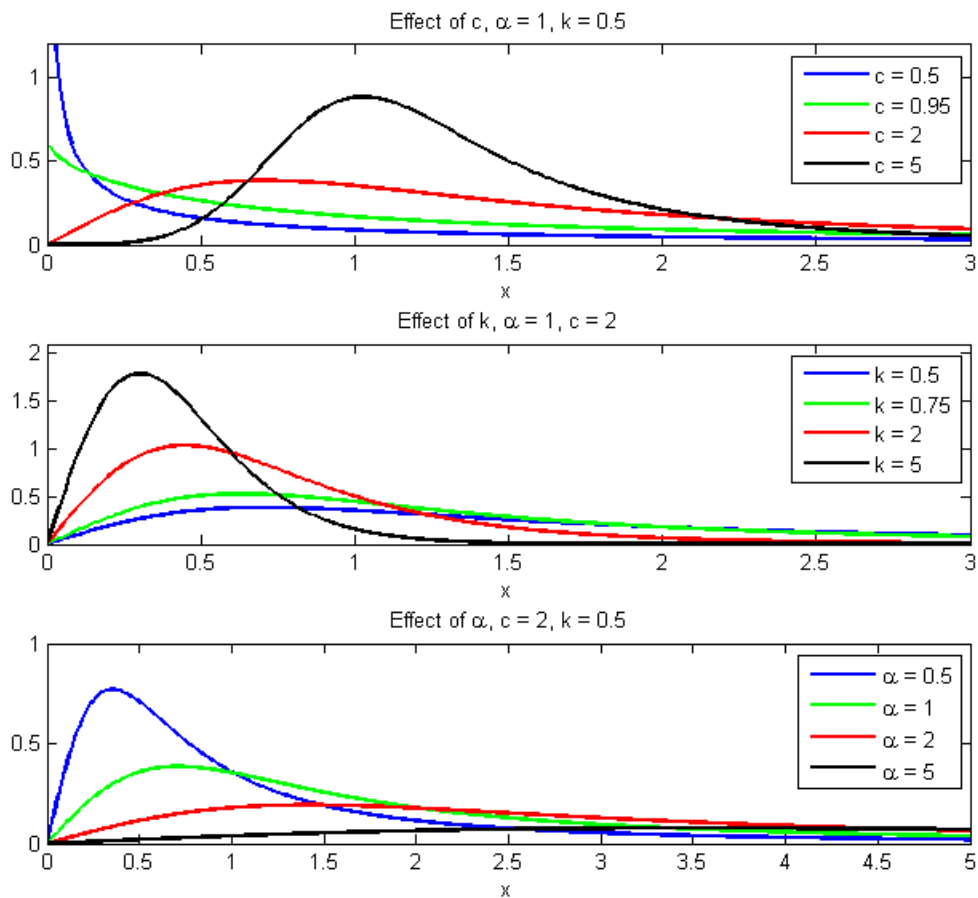
axC = subplot(3,1,1);
pC(i) = plot(X,pdf1(i,:),colors(i),'LineWidth',2);
title('Effect of c, \alpha = 1, k = 0.5'),xlabel('x')
hold on

axK = subplot(3,1,2);
pK(i) = plot(X,pdf2(i,:),colors(i),'LineWidth',2);
title('Effect of k, \alpha = 1, c = 2'),xlabel('x')
hold on

axAlpha = subplot(3,1,3);
pAlpha(i) = plot(X,pdf3(i,:),colors(i),'LineWidth',2);
title('Effect of \alpha, c = 2, k = 0.5'),xlabel('x')
hold on
end

set(axC,'XLim',[0 3],'YLim',[0 1.2]);
set(axK,'XLim',[0 3],'YLim',[0 2.1]);
set(axAlpha,'XLim',[0 5],'YLim',[0 1]);

legend(axC,'c=0.5','c=0.95','c=2','c=5');
legend(axK,'k=0.5','k=0.75','k=2','k=5');
legend(axAlpha,'\alpha=0.5','\alpha=1','\alpha=2','\alpha=5');
```



This figure illustrates how the shape and scale of the Burr distribution changes for different values of its parameters.

Survival and Hazard Functions of Burr Distribution

This example shows how to find and plot the survival and hazard functions for a sample coming from a Burr distribution.

1. Generate the data.

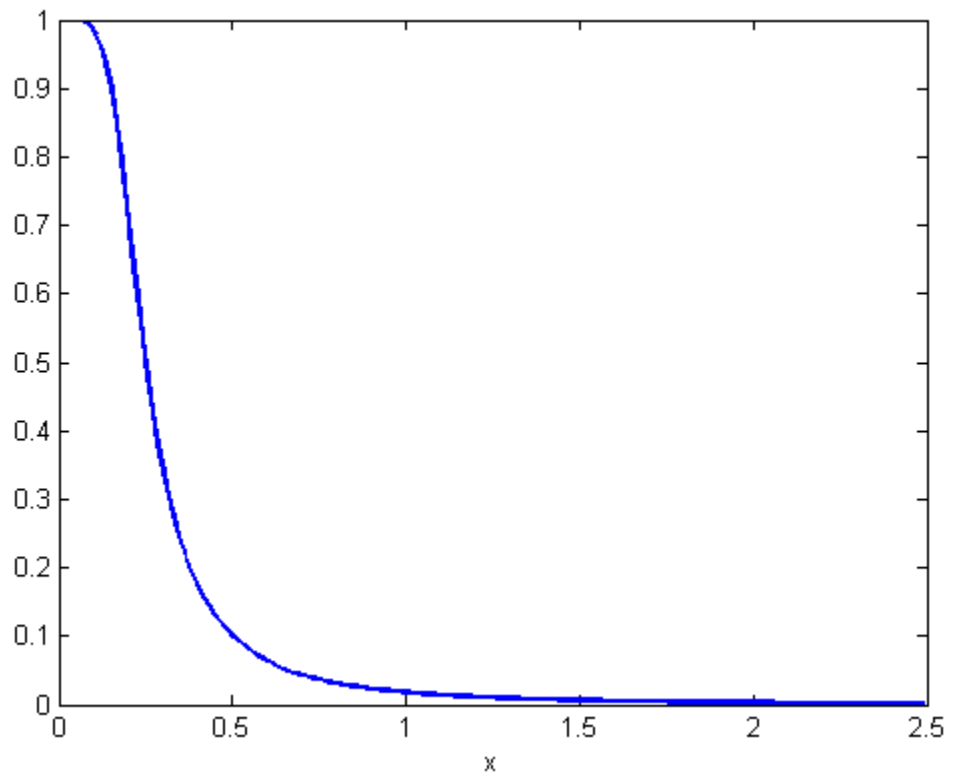
```
X = 0:0.015:2.5;
```

2. Evaluate the pdf and cdf of data in X.

```
Xpdf = pdf('burr',X,0.2,5,0.5);  
Xcdf = cdf('burr',X,0.2,5,0.5);
```

3. Evaluate and plot the survival function of data in X.

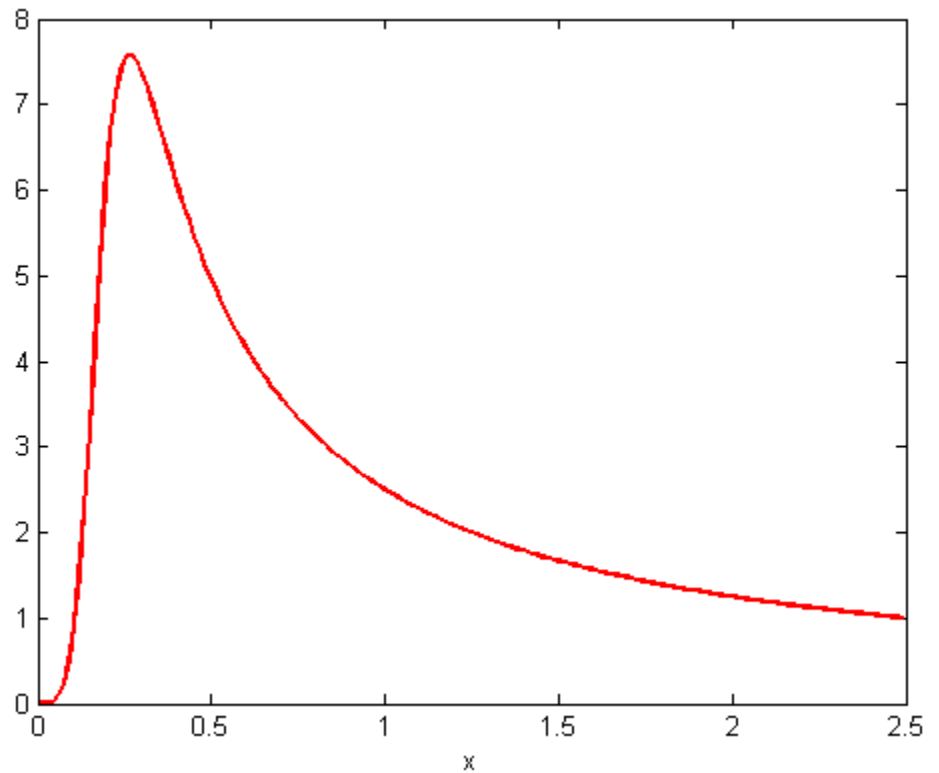
```
S = 1.-Xcdf; % survival function  
plot(X,S,'LineWidth',2)  
xlabel('x')
```



Survival function

4. Evaluate and plot the hazard function of data in X.

```
H = Xpdf./S; % hazard function
plot(X,H,'r','LineWidth',2)
xlabel('x')
```



Hazard function

Divergence of Parameter Estimates

This example shows how to interpret the display when the parameter estimates diverge when fitting a Burr distribution to input data.

1. Generate sample data from the Weibull distribution with parameters 0.5 and 2.

```
rng('default') % for reproducibility
X = wblrnd(0.5,2,100,1);
```

2. Fit a Burr distribution.

```
PD = fitdist(X,'burr');
```

```
Error using addburr>burrfit (line 566)
```

The data are not fit by a Burr distribution with finite parameters. The maximum likelihood fit is provided by the $k \rightarrow \infty$, $\alpha \rightarrow \infty$ limiting form of the Burr distribution: a Weibull distribution with the parameters below.

```
  a (scale): 0.476817
  b (shape): 1.96219
```

```
Error in fitdata (line 24)
```

```
    p = F(x,fixedparams{:},0.05,opts{:});
```

```
Error in ProbDistUnivParam.fit (line 94)
```

```
pd = fitdata(pd,spec,x,cens,freq,fixedparams,options);
```

```
Error in fitdist (line 124)
```

```
pd =
    ProbDistUnivParam.fit(x,distname,'cens',cens,'freq',freq,args{:});
```

The error message tells you that the Weibull family seems to fit the data better and gives you the parameter estimates from a Weibull fit. You can use those estimates directly. If you need covariance estimates for the parameters or other information about the fit, you can refit a Weibull distribution to the data.

3. Fit a Weibull distribution to the data and find the confidence intervals for the parameter estimates.

```
PD = fitdist(X,'weibull');
paramci(PD)
```

```
ans =
```

0.4291 1.6821
0.5298 2.2890

These are the 95% confidence intervals of the parameter estimates for the Weibull distribution fit.

References

- [1] Burr, Irving W. “Cumulative frequency functions.” *The Annals of Mathematical Statistics*, Vol. 13, Number 2, 1942, pp. 215–232.
- [2] Tadikamalla, Pandu R. “A look at the Burr and related distributions.” *International Statistical Review*, Vol. 48, Number 3, 1980, pp. 337–344.
- [3] Rodriguez, Robert N. “A guide to the Burr type XII distributions.” *Biometrika*, Vol. 64, Number 1, 1977, pp. 129–134.
- [4] AL-Hussaini, Essam K. “A characterization of the Burr type XII distribution”. *Appl. Math. Lett.* Vol. 4, Number 1, 1991, pp. 59–61.
- [5] Grammig, Joachim and Kai-Oliver Maurer. “Non-monotonic hazard functions and the autoregressive conditional duration model.” *Econometrics Journal*, Vol. 3, 2000, pp. 16–38.

See Also

“Continuous Distributions (Data)” on page 5-4

Chi-Square Distribution

In this section...

“Definition” on page B-25

“Background” on page B-25

“Example” on page B-26

“See Also” on page B-26

Definition

The χ^2 pdf is

$$y = f(x | v) = \frac{x^{(v-2)/2} e^{-x/2}}{2^{v/2} \Gamma(v/2)}$$

where $\Gamma(\cdot)$ is the Gamma function, and v is the degrees of freedom.

Background

The χ^2 distribution is a special case of the gamma distribution where $b = 2$ in the equation for gamma distribution below.

$$y = f(x | a, b) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}}$$

The χ^2 distribution gets special attention because of its importance in normal sampling theory. If a set of n observations is normally distributed with variance σ^2 , and s^2 is the sample standard deviation, then

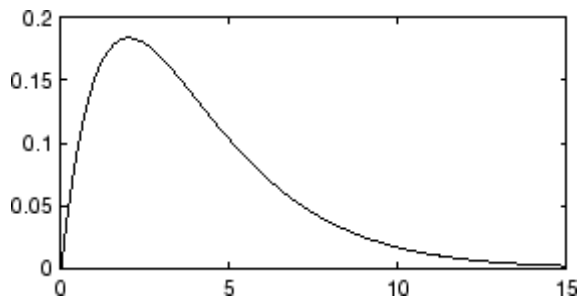
$$\frac{(n-1)s^2}{\sigma^2} \sim \chi^2(n-1)$$

This relationship is used to calculate confidence intervals for the estimate of the normal parameter σ^2 in the function `normfit`.

Example

The χ^2 distribution is skewed to the right especially for few degrees of freedom (ν). The plot shows the χ^2 distribution with four degrees of freedom.

```
x = 0:0.2:15;  
y = chi2pdf(x,4);  
plot(x,y)
```



See Also

“Continuous Distributions (Statistics)” on page 5-7

Copulas

See “Copulas: Generate Correlated Samples” on page 5-108.

Custom Distributions

User-defined custom distributions, created using files and function handles, are supported by the Statistics Toolbox functions `pdf`, `cdf`, `icdf`, and `mle`, and the Statistics Toolbox GUI `dfittool`.

Exponential Distribution

In this section...

“Definition” on page B-29

“Background” on page B-29

“Parameters” on page B-29

“Example” on page B-30

“See Also” on page B-31

Definition

The exponential pdf is

$$y = f(x | \mu) = \frac{1}{\mu} e^{-\frac{x}{\mu}}$$

Background

Like the chi-square distribution, the exponential distribution is a special case of the gamma distribution (obtained by setting $\alpha = 1$)

$$y = f(x | \alpha, b) = \frac{1}{b^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{b}}$$

where $\Gamma(\cdot)$ is the Gamma function.

The exponential distribution is special because of its utility in modeling events that occur randomly over time. The main application area is in studies of lifetimes.

Parameters

Suppose you are stress testing light bulbs and collecting data on their lifetimes. You assume that these lifetimes follow an exponential distribution.

You want to know how long you can expect the average light bulb to last. Parameter estimation is the process of determining the parameters of the exponential distribution that fit this data best in some sense.

One popular criterion of goodness is to maximize the likelihood function. The likelihood has the same form as the exponential pdf above. But for the pdf, the parameters are known constants and the variable is x . The likelihood function reverses the roles of the variables. Here, the sample values (the x 's) are already observed. So they are the fixed constants. The variables are the unknown parameters. MLE involves calculating the values of the parameters that give the highest likelihood given the particular set of data.

The function `expfit` returns the MLEs and confidence intervals for the parameters of the exponential distribution. Here is an example using random numbers from the exponential distribution with $\mu = 700$.

```
lifetimes = exprnd(700,100,1);  
[muhat, muc1] = expfit(lifetimes)
```

```
muhat =
```

```
672.8207
```

```
muc1 =
```

```
547.4338
```

```
810.9437
```

The MLE for parameter μ is 672, compared to the true value of 700. The 95% confidence interval for μ goes from 547 to 811, which includes the true value.

In the life tests you do not know the true value of μ so it is nice to have a confidence interval on the parameter to give a range of likely values.

Example

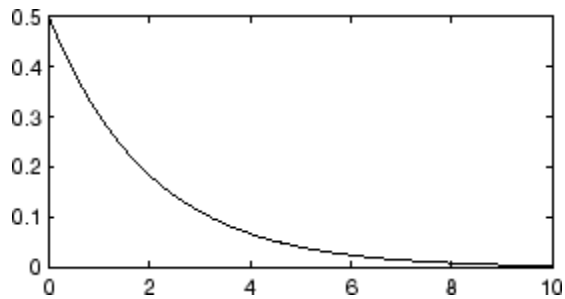
For exponentially distributed lifetimes, the probability that an item will survive an extra unit of time is independent of the current age of the item. The example shows a specific case of this special property.

```
1 = 10:10:60;
```

```
lpd = 1+0.1;  
deltap = (expcdf(lpd,50)-expcdf(1,50))./(1-expcdf(1,50))  
  
deltap =  
    0.0020    0.0020    0.0020    0.0020    0.0020    0.0020
```

The following commands generate a plot of the exponential pdf with its parameter (and mean), μ , set to 2.

```
x = 0:0.1:10;  
y = exppdf(x,2);  
plot(x,y)
```



See Also

“Continuous Distributions (Data)” on page 5-4

Extreme Value Distribution

In this section...

“Definition” on page B-32

“Background” on page B-32

“Parameters” on page B-34

“Example” on page B-35

“See Also” on page B-37

Definition

The probability density function for the extreme value distribution with location parameter μ and scale parameter σ is

$$y = f(x | \mu, \sigma) = \sigma^{-1} \exp\left(\frac{x - \mu}{\sigma}\right) \exp\left(-\exp\left(\frac{x - \mu}{\sigma}\right)\right)$$

This form of the probability density function is suitable for modeling the minimum value. To model the maximum value, use the negative of the original values.

If T has a Weibull distribution with parameters a and b , then $\log T$ has an extreme value distribution with parameters $\mu = \log a$ and $\sigma = 1/b$.

Background

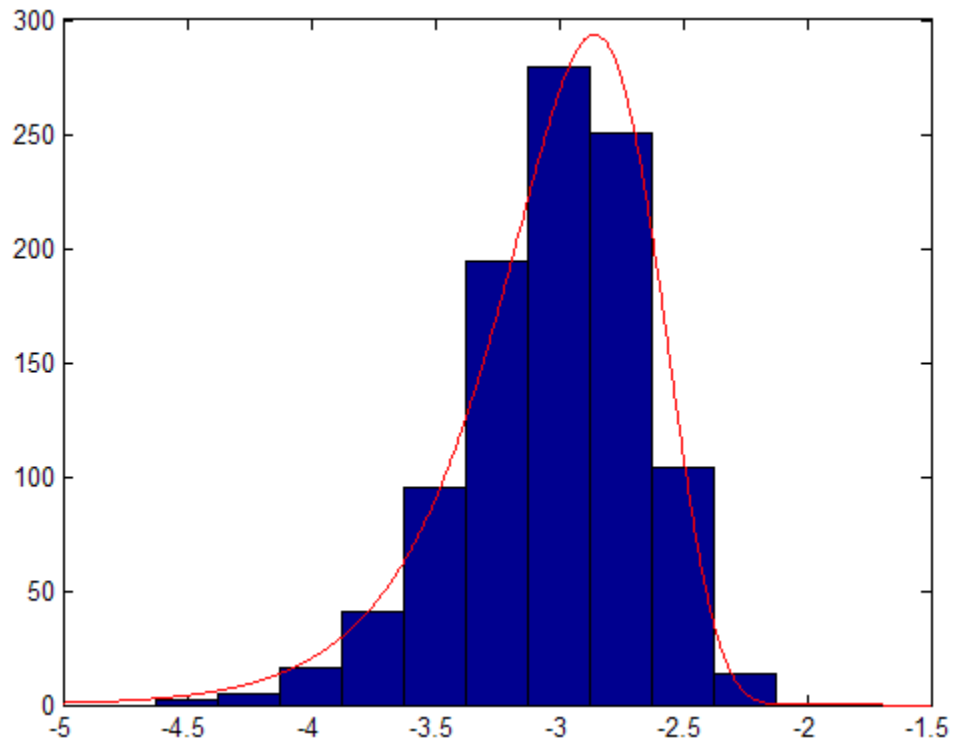
Extreme value distributions are often used to model the smallest or largest value among a large set of independent, identically distributed random values representing measurements or observations. The extreme value distribution is appropriate for modeling the smallest value from a distribution whose tails decay exponentially fast, for example, the normal distribution. It can also model the largest value from a distribution, such as the normal or exponential distributions, by using the negative of the original values.

For example, the following fits an extreme value distribution to minimum values taken over 1000 sets of 500 observations from a normal distribution:


```

xMinima = min(randn(1000,500), [], 2);
paramEstsMinima = evfit(xMinima);
y = linspace(-5,-1.5,1001);
hist(xMinima,-4.75:.25:-1.75);
p = evpdf(y,paramEstsMinima(1),paramEstsMinima(2));
line(y,.25*length(xMinima)*p,'color','r')

```

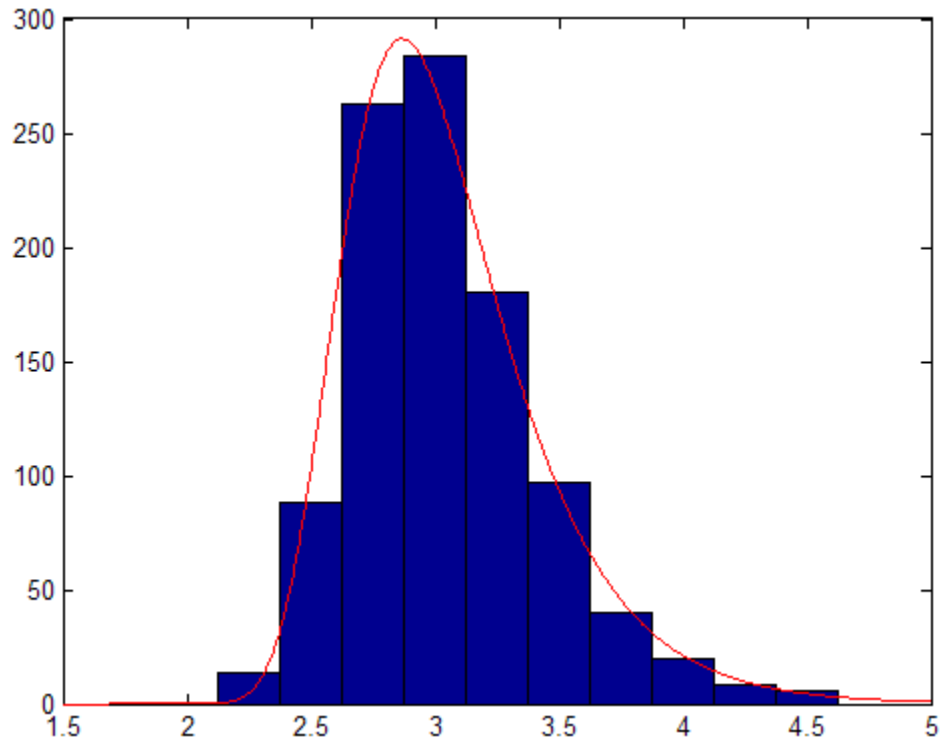


The following fits an extreme value distribution to the maximum values in each set of observations:

```

xMaxima = max(randn(1000,500), [], 2);
paramEstsMaxima = evfit(-xMaxima);
y = linspace(1.5,5,1001);
hist(xMaxima,1.75:.25:4.75);
p = evpdf(-y,paramEstsMaxima(1),paramEstsMaxima(2));
line(y,.25*length(xMaxima)*p,'color','r')

```



Although the extreme value distribution is most often used as a model for extreme values, you can also use it as a model for other types of continuous data. For example, extreme value distributions are closely related to the Weibull distribution. If T has a Weibull distribution, then $\log(T)$ has a type 1 extreme value distribution.

Parameters

The function `evfit` returns the maximum likelihood estimates (MLEs) and confidence intervals for the parameters of the extreme value distribution. The following example shows how to fit some sample data using `evfit`, including estimates of the mean and variance from the fitted distribution.

Suppose you want to model the size of the smallest washer in each batch of 1000 from a manufacturing process. If you believe that the sizes are

independent within and between each batch, you can fit an extreme value distribution to measurements of the minimum diameter from a series of eight experimental batches. The following code returns the MLEs of the distribution parameters as `parmhat` and the confidence intervals as the columns of `parmci`.

```
x = [19.774 20.141 19.44 20.511 21.377 19.003 19.66 18.83];  
[parmhat, parmci] = evfit(x)
```

```
parmhat =  
    20.2506    0.8223
```

```
parmci =  
    19.644 0.49861  
    20.857 1.3562
```

You can find mean and variance of the extreme value distribution with these parameters using the function `evstat`.

```
[meanfit, varfit] = evstat(parmhat(1),parmhat(2))
```

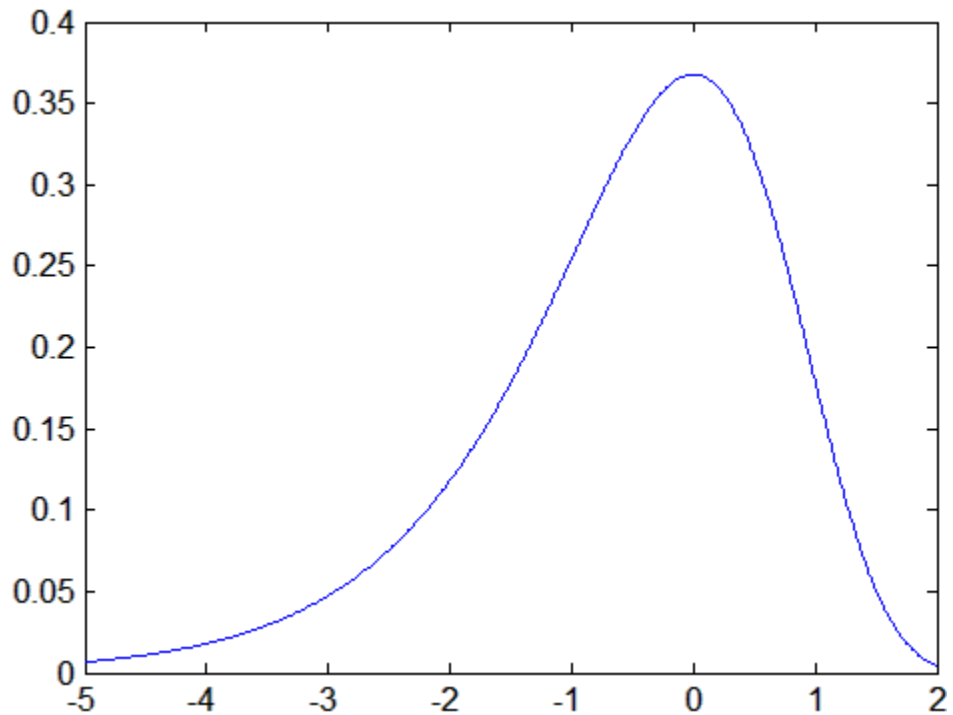
```
meanfit =  
    19.776
```

```
varfit =  
    1.1123
```

Example

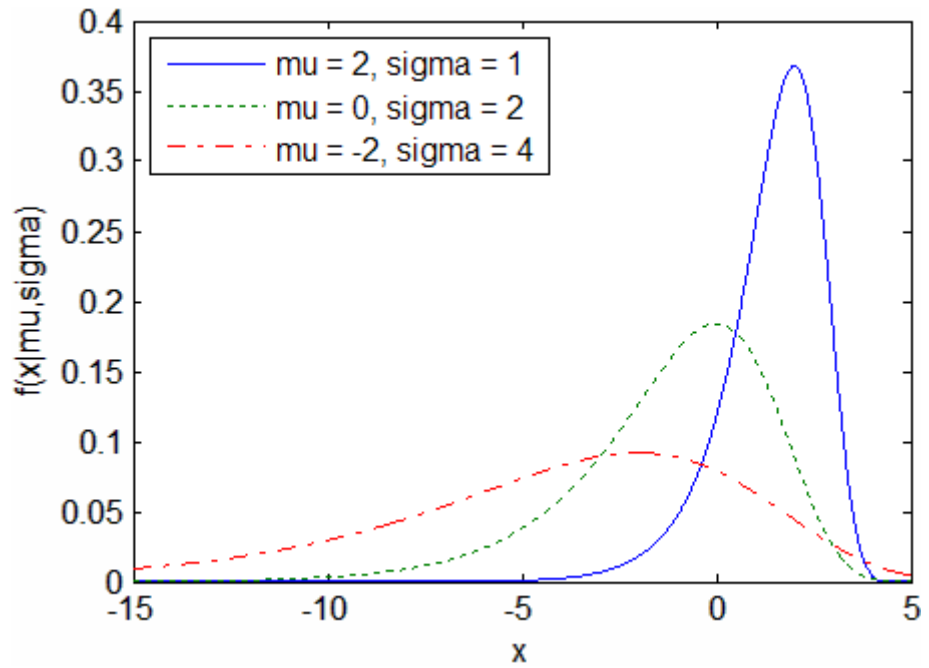
The following code generates a plot of the pdf for the extreme value distribution.

```
t = [-5:.01:2];  
y = evpdf(t);  
plot(t,y)
```



The extreme value distribution is skewed to the left, and its general shape remains the same for all parameter values. The location parameter, μ , shifts the distribution along the real line, and the scale parameter, σ , expands or contracts the distribution. This example plots the probability function for different combinations of μ and σ .

```
x = -15:.01:5;
plot(x,evpdf(x,2,1),'-', ...
      x,evpdf(x,0,2),':', ...
      x,evpdf(x,-2,4),'-.');
legend({'mu = 2, sigma = 1', ...
       'mu = 0, sigma = 2', ...
       'mu = -2, sigma = 4'}, ...
       'Location','NW')
xlabel('x')
ylabel('f(x|mu,sigma)')
```

**See Also**

“Continuous Distributions (Data)” on page 5-4

F Distribution

In this section...

“Definition” on page B-38

“Background” on page B-38

“Example” on page B-39

“See Also” on page B-39

Definition

The pdf for the F distribution is

$$y = f(x | v_1, v_2) = \frac{\Gamma\left[\frac{(v_1 + v_2)}{2}\right]}{\Gamma\left(\frac{v_1}{2}\right)\Gamma\left(\frac{v_2}{2}\right)} \left(\frac{v_1}{v_2}\right)^{\frac{v_1}{2}} \frac{x^{\frac{v_1-2}{2}}}{\left[1 + \left(\frac{v_1}{v_2}\right)x\right]^{\frac{v_1+v_2}{2}}}$$

where $\Gamma(\cdot)$ is the Gamma function.

Background

The F distribution has a natural relationship with the chi-square distribution. If χ_1 and χ_2 are both chi-square with v_1 and v_2 degrees of freedom respectively, then the statistic F below is F -distributed.

$$F(v_1, v_2) = \frac{\chi_1 / v_1}{\chi_2 / v_2}$$

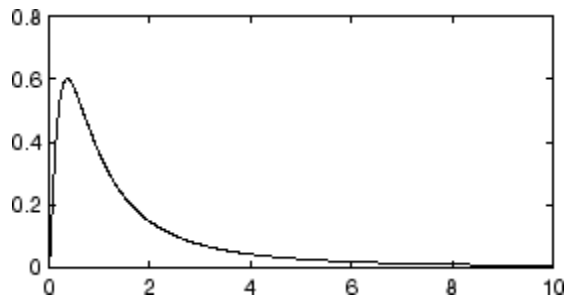
The two parameters, v_1 and v_2 , are the numerator and denominator degrees of freedom. That is, v_1 and v_2 are the number of independent pieces of information used to calculate χ_1 and χ_2 , respectively.

Example

The most common application of the F distribution is in standard tests of hypotheses in analysis of variance and regression.

The plot shows that the F distribution exists on the positive real numbers and is skewed to the right.

```
x = 0:0.01:10;  
y = fpdf(x,5,3);  
plot(x,y)
```



See Also

“Continuous Distributions (Statistics)” on page 5-7

Gamma Distribution

In this section...
“Definition” on page B-40
“Background” on page B-40
“Parameters” on page B-41
“Example” on page B-42
“See Also” on page B-42

Definition

The gamma pdf is

$$y = f(x | a, b) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}}$$

where $\Gamma(\cdot)$ is the Gamma function.

Background

The gamma distribution models sums of exponentially distributed random variables.

The gamma distribution family is based on two parameters. The chi-square and exponential distributions, which are children of the gamma distribution, are one-parameter distributions that fix one of the two gamma parameters.

The gamma distribution has the following relationship with the incomplete Gamma function.

$$f(x | a, b) = \text{gammainc}\left(\frac{x}{b}, a\right)$$

When α is large, the gamma distribution closely approximates a normal distribution with the advantage that the gamma distribution has density only for positive real numbers.

Parameters

Suppose you are stress testing computer memory chips and collecting data on their lifetimes. You assume that these lifetimes follow a gamma distribution. You want to know how long you can expect the average computer memory chip to last. Parameter estimation is the process of determining the parameters of the gamma distribution that fit this data best in some sense.

One popular criterion of goodness is to maximize the likelihood function. The likelihood has the same form as the gamma pdf above. But for the pdf, the parameters are known constants and the variable is x . The likelihood function reverses the roles of the variables. Here, the sample values (the x 's) are already observed. So they are the fixed constants. The variables are the unknown parameters. MLE involves calculating the values of the parameters that give the highest likelihood given the particular set of data.

The function `gamfit` returns the MLEs and confidence intervals for the parameters of the gamma distribution. Here is an example using random numbers from the gamma distribution with $\alpha = 10$ and $b = 5$.

```
lifetimes = gamrnd(10,5,100,1);
[phat, pci] = gamfit(lifetimes)
```

```
phat =
```

```
    10.9821    4.7258
```

```
pci =
```

```
    7.4001    3.1543
   14.5640    6.2974
```

Note $\text{phat}(1) = \hat{a}$ and $\text{phat}(2) = \hat{b}$. The MLE for parameter a is 10.98, compared to the true value of 10. The 95% confidence interval for a goes from 7.4 to 14.6, which includes the true value.

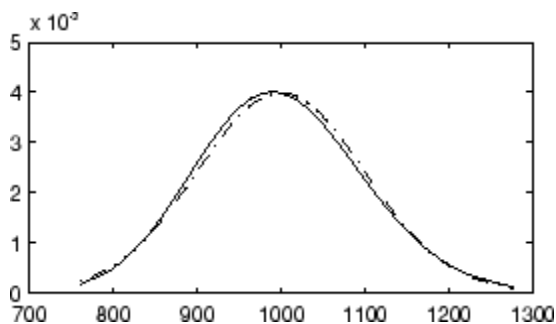
Similarly the MLE for parameter b is 4.7, compared to the true value of 5. The 95% confidence interval for b goes from 3.2 to 6.3, which also includes the true value.

In the life tests you do not know the true value of a and b so it is nice to have a confidence interval on the parameters to give a range of likely values.

Example

In the example the gamma pdf is plotted with the solid line. The normal pdf has a dashed line type.

```
x = gaminv( (0.005:0.01:0.995), 100, 10);  
y = gampdf(x, 100, 10);  
y1 = normpdf(x, 1000, 100);  
plot(x, y, '-', x, y1, '-.-')
```



See Also

“Continuous Distributions (Data)” on page 5-4

Gaussian Distribution

See “Normal Distribution” on page B-96.

Gaussian Mixture Distributions

See the discussion of the `gmdistribution` class in “Gaussian Mixture Models” on page 5-100.

Generalized Extreme Value Distribution

In this section...

“Definition” on page B-45

“Background” on page B-45

“Parameters” on page B-46

“Example” on page B-47

“See Also” on page B-49

Definition

The probability density function for the generalized extreme value distribution with location parameter μ , scale parameter σ , and shape parameter $k \neq 0$ is

$$y = f(x | k, \mu, \sigma) = \left(\frac{1}{\sigma}\right) \exp\left(-\left(1 + k \frac{(x - \mu)}{\sigma}\right)^{\frac{1}{k}}\right) \left(1 + k \frac{(x - \mu)}{\sigma}\right)^{-1 - \frac{1}{k}}$$

for

$$1 + k \frac{(x - \mu)}{\sigma} > 0$$

$k > 0$ corresponds to the Type II case, while $k < 0$ corresponds to the Type III case. For $k = 0$, corresponding to the Type I case, the density is

$$y = f(x | 0, \mu, \sigma) = \left(\frac{1}{\sigma}\right) \exp\left(-\exp\left(-\frac{(x - \mu)}{\sigma}\right) - \frac{(x - \mu)}{\sigma}\right)$$

Background

Like the extreme value distribution, the generalized extreme value distribution is often used to model the smallest or largest value among a large set of independent, identically distributed random values representing measurements or observations. For example, you might have batches of 1000

washers from a manufacturing process. If you record the size of the largest washer in each batch, the data are known as block maxima (or minima if you record the smallest). You can use the generalized extreme value distribution as a model for those block maxima.

The generalized extreme value combines three simpler distributions into a single form, allowing a continuous range of possible shapes that includes all three of the simpler distributions. You can use any one of those distributions to model a particular dataset of block maxima. The generalized extreme value distribution allows you to “let the data decide” which distribution is appropriate.

The three cases covered by the generalized extreme value distribution are often referred to as the Types I, II, and III. Each type corresponds to the limiting distribution of block maxima from a different class of underlying distributions. Distributions whose tails decrease exponentially, such as the normal, lead to the Type I. Distributions whose tails decrease as a polynomial, such as Student’s t , lead to the Type II. Distributions whose tails are finite, such as the beta, lead to the Type III.

Types I, II, and III are sometimes also referred to as the Gumbel, Frechet, and Weibull types, though this terminology can be slightly confusing. The Type I (Gumbel) and Type III (Weibull) cases actually correspond to the mirror images of the usual Gumbel and Weibull distributions, for example, as computed by the functions `evcdf` and `evfit`, or `wblcdf` and `wblfit`, respectively. Finally, the Type II (Frechet) case is equivalent to taking the reciprocal of values from a standard Weibull distribution.

Parameters

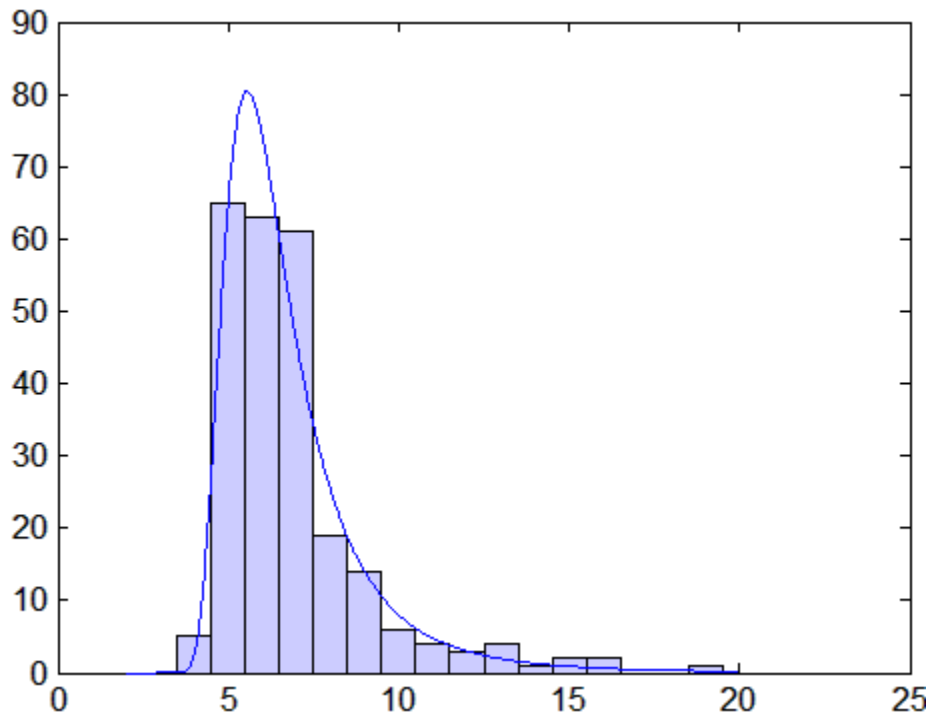
If you generate 250 blocks of 1000 random values drawn from Student’s t distribution with 5 degrees of freedom, and take their maxima, you can fit a generalized extreme value distribution to those maxima.

```
blocksize = 1000;
nblocks = 250;
t = trnd(5,blocksize,nblocks);
x = max(t); % 250 column maxima
paramEsts = gevfit(x)
paramEsts =
```

0.2438 1.1760 5.8045

Notice that the shape parameter estimate (the first element) is positive, which is what you would expect based on block maxima from a Student's t distribution.

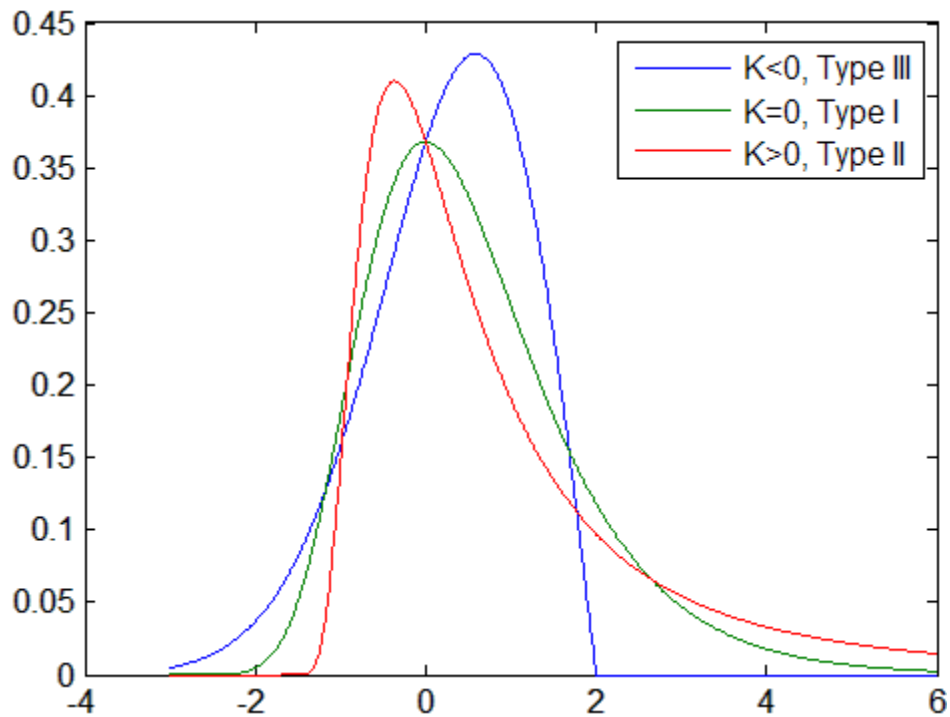
```
hist(x,2:20);
set(get(gca,'child'),'FaceColor',[.8 .8 1]);
xgrid = linspace(2,20,1000);
line(xgrid,nblocks*...
      gevpdf(xgrid,paramEsts(1),paramEsts(2),paramEsts(3)));
```



Example

The following code generates examples of probability density functions for the three basic forms of the generalized extreme value distribution.

```
x = linspace(-3,6,1000);
y1 = gevpdf(x,-.5,1,0);
y2 = gevpdf(x,0,1,0);
y3 = gevpdf(x,.5,1,0);
plot(x,y1,'-', x,y2,'-', x,y3,'-');
legend({'K<0, Type III' 'K=0, Type I' 'K>0, Type II'});
```



Notice that for $k > 0$, the distribution has zero probability density for x such that

$$x < -\frac{\sigma}{k} + \mu$$

For $k < 0$, the distribution has zero probability density for

$$x > -\frac{\sigma}{k} + \mu$$

For $k = 0$, there is no upper or lower bound.

See Also

“Continuous Distributions (Data)” on page 5-4

Generalized Pareto Distribution

In this section...

“Definition” on page B-50

“Background” on page B-50

“Parameters” on page B-51

“Example” on page B-52

“See Also” on page B-53

Definition

The probability density function for the generalized Pareto distribution with shape parameter $k \neq 0$, scale parameter σ , and threshold parameter θ , is

$$y = f(x | k, \sigma, \theta) = \left(\frac{1}{\sigma} \right) \left(1 + k \frac{(x - \theta)}{\sigma} \right)^{-1 - \frac{1}{k}}$$

for $\theta < x$, when $k > 0$, or for $\theta < x < -\sigma/k$ when $k < 0$.

For $k = 0$, the density is

$$y = f(x | 0, \sigma, \theta) = \left(\frac{1}{\sigma} \right) e^{-\frac{(x - \theta)}{\sigma}}$$

for $\theta < x$.

If $k = 0$ and $\theta = 0$, the generalized Pareto distribution is equivalent to the exponential distribution. If $k > 0$ and $\theta = \sigma/k$, the generalized Pareto distribution is equivalent to the Pareto distribution.

Background

Like the exponential distribution, the generalized Pareto distribution is often used to model the tails of another distribution. For example, you might have washers from a manufacturing process. If random influences in the process lead to differences in the sizes of the washers, a standard probability

distribution, such as the normal, could be used to model those sizes. However, while the normal distribution might be a good model near its mode, it might not be a good fit to real data in the tails and a more complex model might be needed to describe the full range of the data. On the other hand, only recording the sizes of washers larger (or smaller) than a certain threshold means you can fit a separate model to those tail data, which are known as *exceedences*. You can use the generalized Pareto distribution in this way, to provide a good fit to extremes of complicated data.

The generalized Pareto distribution allows a continuous range of possible shapes that includes both the exponential and Pareto distributions as special cases. You can use either of those distributions to model a particular dataset of exceedences. The generalized Pareto distribution allows you to “let the data decide” which distribution is appropriate.

The generalized Pareto distribution has three basic forms, each corresponding to a limiting distribution of exceedence data from a different class of underlying distributions.

- Distributions whose tails decrease exponentially, such as the normal, lead to a generalized Pareto shape parameter of zero.
- Distributions whose tails decrease as a polynomial, such as Student’s t , lead to a positive shape parameter.
- Distributions whose tails are finite, such as the beta, lead to a negative shape parameter.

The generalized Pareto distribution is used in the tails of distribution fit objects of the `paretotails` class.

Parameters

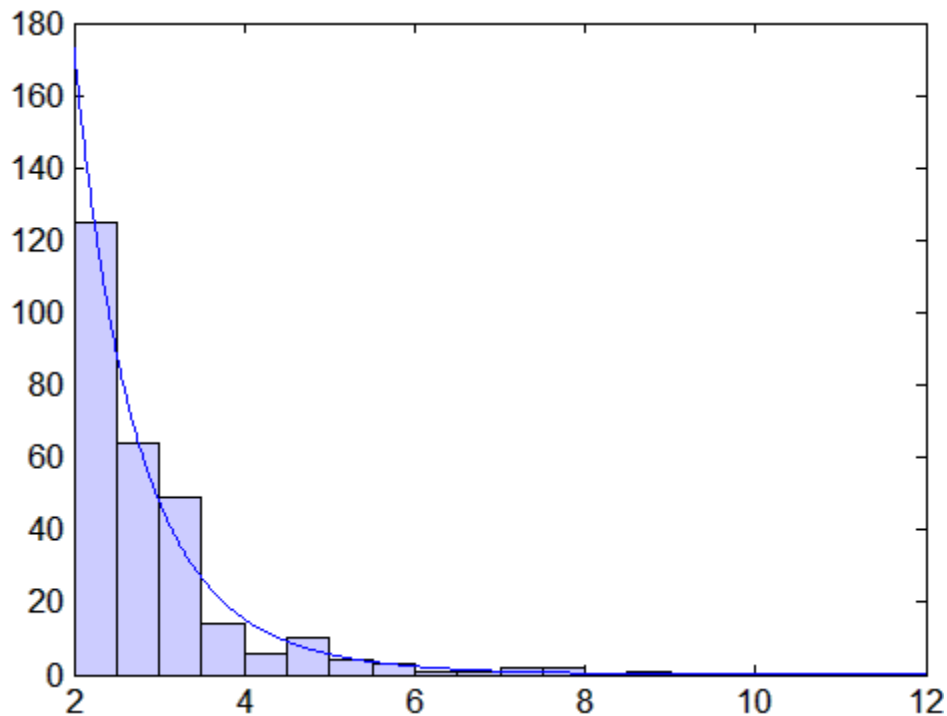
If you generate a large number of random values from a Student’s t distribution with 5 degrees of freedom, and then discard everything less than 2, you can fit a generalized Pareto distribution to those exceedences.

```
t = trnd(5,5000,1);
y = t(t > 2) - 2;
paramEsts = gpfitt(y)
paramEsts =
```

0.1267 0.8134

Notice that the shape parameter estimate (the first element) is positive, which is what you would expect based on exceedences from a Student's *t* distribution.

```
hist(y+2,2.25:.5:11.75);
set(get(gca,'child'),'FaceColor',[.8 .8 1])
xgrid = linspace(2,12,1000);
line(xgrid,.5*length(y)*...
      gppdf(xgrid,paramEsts(1),paramEsts(2),2));
```



Example

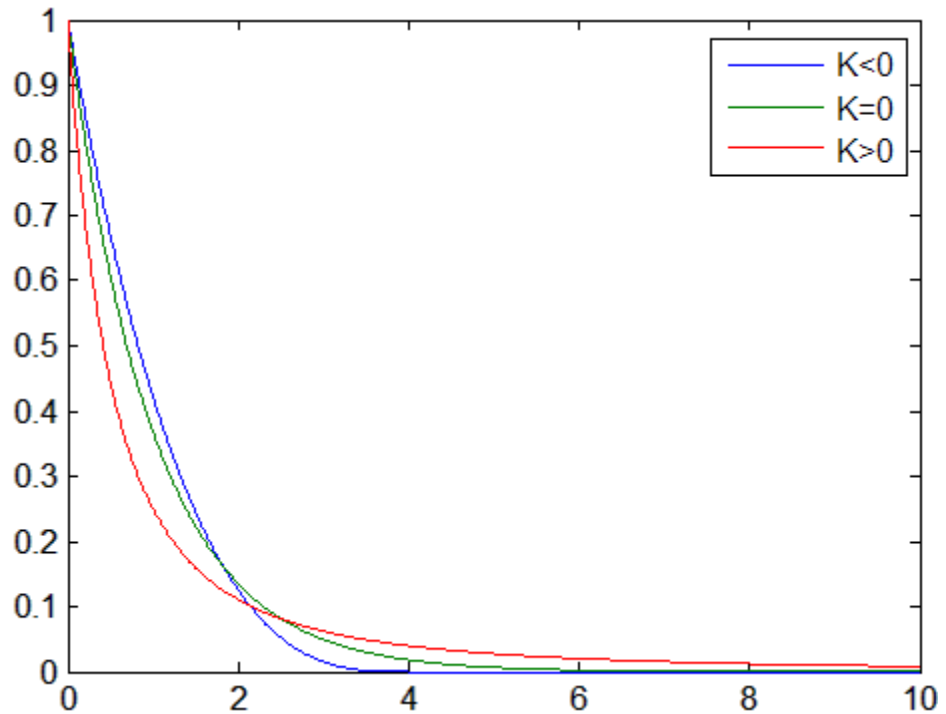
The following code generates examples of the probability density functions for the three basic forms of the generalized Pareto distribution.

```
x = linspace(0,10,1000);
```

```

y1 = gppdf(x, -.25,1,0);
y2 = gppdf(x,0,1,0);
y3 = gppdf(x,1,1,0)
plot(x,y1,'- ', x,y2,'- ', x,y3,'- ')
legend({'K<0' 'K=0' 'K>0'});

```



Notice that for $k < 0$, the distribution has zero probability density for $x > -\frac{\sigma}{k}$, while for $k \geq 0$, there is no upper bound.

See Also

“Continuous Distributions (Data)” on page 5-4

Geometric Distribution

In this section...
“Definition” on page B-54
“Background” on page B-54
“Example” on page B-54
“See Also” on page B-55

Definition

The geometric pdf is

$$y = f(x | p) = pq^x I_{(0,1,\dots)}(x)$$

where $q = 1 - p$. The geometric distribution is a special case of the negative binomial distribution, with $r = 1$.

Background

The geometric distribution is discrete, existing only on the nonnegative integers. It is useful for modeling the runs of consecutive successes (or failures) in repeated independent trials of a system.

The geometric distribution models the number of successes before one failure in an independent succession of tests where each test results in success or failure.

Example

Suppose the probability of a five-year-old battery failing in cold weather is 0.03. What is the probability of starting 25 consecutive days during a long cold snap?

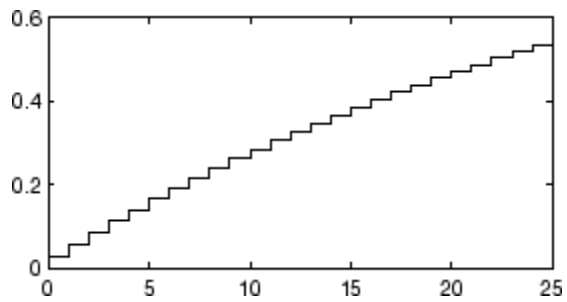
1 - geocdf(25,0.03)

ans =

0.4530

The plot shows the cdf for this scenario.

```
x = 0:25;  
y = geocdf(x,0.03);  
stairs(x,y)
```



See Also

“Discrete Distributions” on page 5-8

Hypergeometric Distribution

In this section...

“Definition” on page B-56

“Background” on page B-56

“Example” on page B-57

“See Also” on page B-57

Definition

The hypergeometric pdf is

$$y = f(x | M, K, n) = \frac{\binom{K}{x} \binom{M-K}{n-x}}{\binom{M}{n}}$$

Background

The hypergeometric distribution models the total number of successes in a fixed-size sample drawn without replacement from a finite population.

The distribution is discrete, existing only for nonnegative integers less than the number of samples or the number of possible successes, whichever is greater. The hypergeometric distribution differs from the binomial only in that the population is finite and the sampling from the population is without replacement.

The hypergeometric distribution has three parameters that have direct physical interpretations.

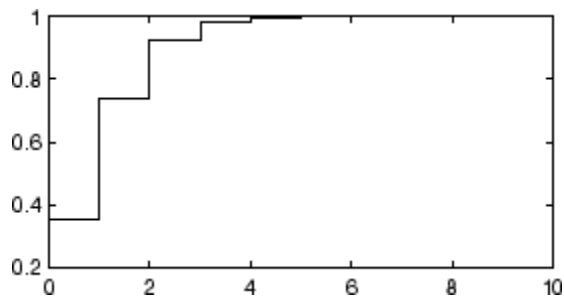
- M is the size of the population.
- K is the number of items with the desired characteristic in the population.
- n is the number of samples drawn.

Sampling “without replacement” means that once a particular sample is chosen, it is removed from the relevant population for all subsequent selections.

Example

The plot shows the cdf of an experiment taking 20 samples from a group of 1000 where there are 50 items of the desired type.

```
x = 0:10;  
y = hygecdf(x,1000,50,20);  
stairs(x,y)
```



See Also

“Discrete Distributions” on page 5-8

Inverse Gaussian Distribution

In this section...
“Definition” on page B-58
“Background” on page B-58
“Parameters” on page B-58
“See Also” on page B-58

Definition

The inverse Gaussian distribution has the density function

$$\sqrt{\frac{\lambda}{2\pi x^3}} \exp\left\{-\frac{\lambda}{2\mu^2 x}(x - \mu)^2\right\}$$

Background

Also known as the Wald distribution, the inverse Gaussian is used to model nonnegative positively skewed data. The distribution originated in the theory of Brownian motion, but has been used to model diverse phenomena. Inverse Gaussian distributions have many similarities to standard Gaussian (normal) distributions, which lead to applications in inferential statistics.

Parameters

See `mle`, `dfittool`.

See Also

“Continuous Distributions (Data)” on page 5-4

Inverse Wishart Distribution

Definition

The probability density function of the d -dimensional Inverse Wishart distribution is given by

$$y = f(X, \Sigma, \nu) = \frac{|T|^{(\nu/2)} e^{\left(-\frac{1}{2}\text{trace}(TX^{-1})\right)}}{2^{(\nu d)/2} \pi^{(d(d-1))/4} |X|^{(\nu+d+1)/2} \Gamma(\nu/2) \dots \Gamma(\nu - (d-1)/2)},$$

where X and T are d -by- d symmetric positive definite matrices, and ν is a scalar greater than or equal to d . While it is possible to define the Inverse Wishart for singular T , the density cannot be written as above.

If a random matrix has a Wishart distribution with parameters T^{-1} and ν , then the inverse of that random matrix has an inverse Wishart distribution with parameters T and ν . The mean of the distribution is given by

$$\frac{1}{\nu - d - 1} T$$

where d is the number of rows and columns in T .

Only random matrix generation is supported for the inverse Wishart, including both singular and nonsingular T .

Background

The inverse Wishart distribution is based on the Wishart distribution. In Bayesian statistics it is used as the conjugate prior for the covariance matrix of a multivariate normal distribution.

Example

Notice that the sampling variability is quite large when the degrees of freedom is small.

```
Tau = [1 .5; .5 2];
df = 10; S1 = iwishrnd(Tau,df)*(df-2-1)
```

```
S1 =  
    1.7959    0.64107  
    0.64107    1.5496
```

```
df = 1000; S2 = iwishrnd(Tau,df)*(df-2-1)
```

```
S2 =  
    0.9842    0.50158  
    0.50158    2.1682
```

See Also

“Wishart Distribution” on page B-119, “Multivariate Distributions” on page 5-9

Johnson System

See “Pearson and Johnson Systems” on page 6-25.

Logistic Distribution

In this section...
“Definition” on page B-62
“Background” on page B-62
“Parameters” on page B-62
“See Also” on page B-62

Definition

The logistic distribution has the density function

$$\frac{e^{-\frac{x-\mu}{\sigma}}}{\sigma \left(1 + e^{-\frac{x-\mu}{\sigma}} \right)^2}$$

with location parameter μ and scale parameter $\sigma > 0$, for all real x .

Background

The logistic distribution originated with Verhulst’s work on demography in the early 1800s. The distribution has been used for various growth models, and is used in logistic regression. It has longer tails and a higher kurtosis than the normal distribution.

Parameters

See `mle`, `dfittool`.

See Also

“Continuous Distributions (Data)” on page 5-4

Loglogistic Distribution

In this section...
“Definition” on page B-63
“Parameters” on page B-63
“See Also” on page B-63

Definition

The variable x has a loglogistic distribution with location parameter μ and scale parameter $\sigma > 0$ if $\ln x$ has a logistic distribution with parameters μ and σ . The relationship is similar to that between the lognormal and normal distribution.

Parameters

See `mle`, `dfittool`.

See Also

“Continuous Distributions (Data)” on page 5-4

Lognormal Distribution

In this section...

“Definition” on page B-64

“Background” on page B-64

“Example” on page B-65

“See Also” on page B-66

Definition

The lognormal pdf is

$$y = f(x | \mu, \sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

Background

The normal and lognormal distributions are closely related. If X is distributed lognormally with parameters μ and σ , then $\log(X)$ is distributed normally with mean μ and standard deviation σ .

The mean m and variance v of a lognormal random variable are functions of μ and σ that can be calculated with the `lognstat` function. They are:

$$m = \exp\left(\mu + \sigma^2 / 2\right)$$

$$v = \exp\left(2\mu + \sigma^2\right)\left(\exp\left(\sigma^2\right) - 1\right)$$

A lognormal distribution with mean m and variance v has parameters

$$\mu = \log\left(m^2 / \sqrt{v + m^2}\right)$$

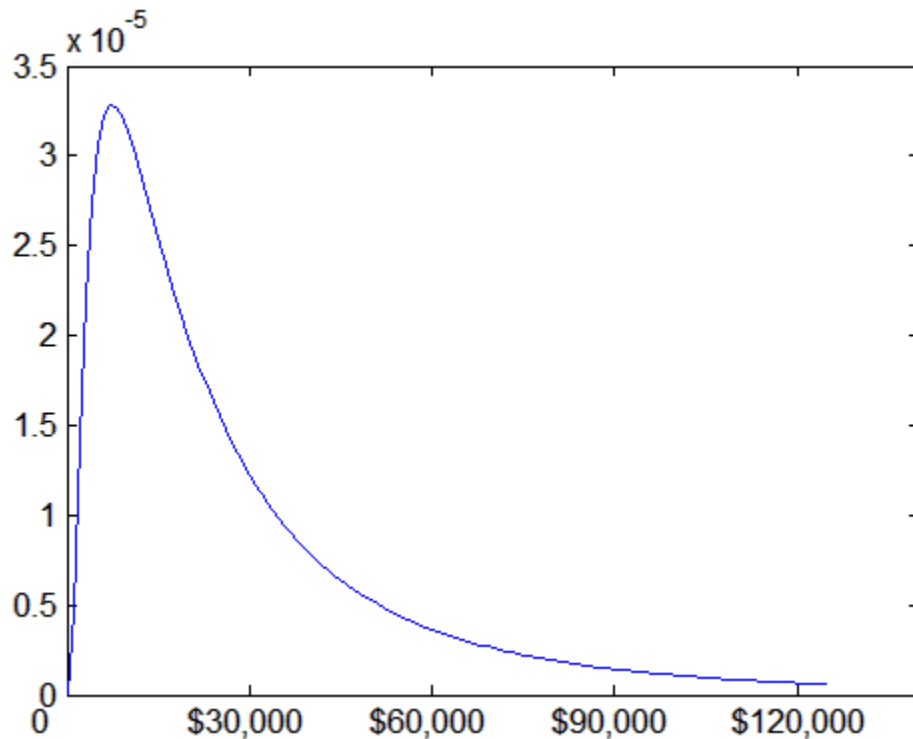
$$\sigma = \sqrt{\log\left(v / m^2 + 1\right)}$$

The lognormal distribution is applicable when the quantity of interest must be positive, since $\log(X)$ exists only when X is positive.

Example

Suppose the income of a family of four in the United States follows a lognormal distribution with $\mu = \log(20,000)$ and $\sigma^2 = 1.0$. Plot the income density.

```
x = (10:1000:125010)';  
y = lognpdf(x, log(20000), 1.0);  
plot(x,y)  
set(gca, 'xtick', [0 30000 60000 90000 120000])  
set(gca, 'xticklabel', {'0', '$30,000', '$60,000', ...  
                        '$90,000', '$120,000'})
```



See Also

“Continuous Distributions (Data)” on page 5-4

Multinomial Distribution

In this section...

“Definition” on page B-67

“Background” on page B-67

“Example” on page B-67

“See Also” on page B-69

Definition

The multinomial pdf is

$$f(x | n, p) = \frac{n!}{x_1! \cdots x_k!} p_1^{x_1} \cdots p_k^{x_k}$$

where $x = (x_1, \dots, x_k)$ gives the number of each of k outcomes in n trials of a process with fixed probabilities $p = (p_1, \dots, p_k)$ of individual outcomes in any one trial. The vector x has non-negative integer components that sum to n . The vector p has non-negative integer components that sum to 1.

Background

The multinomial distribution is a generalization of the binomial distribution. The binomial distribution gives the probability of the number of “successes” and “failures” in n independent trials of a two-outcome process. The probability of “success” and “failure” in any one trial is given by the fixed probabilities p and $q = 1-p$. The multinomial distribution gives the probability of each combination of outcomes in n independent trials of a k -outcome process. The probability of each outcome in any one trial is given by the fixed probabilities p_1, \dots, p_k .

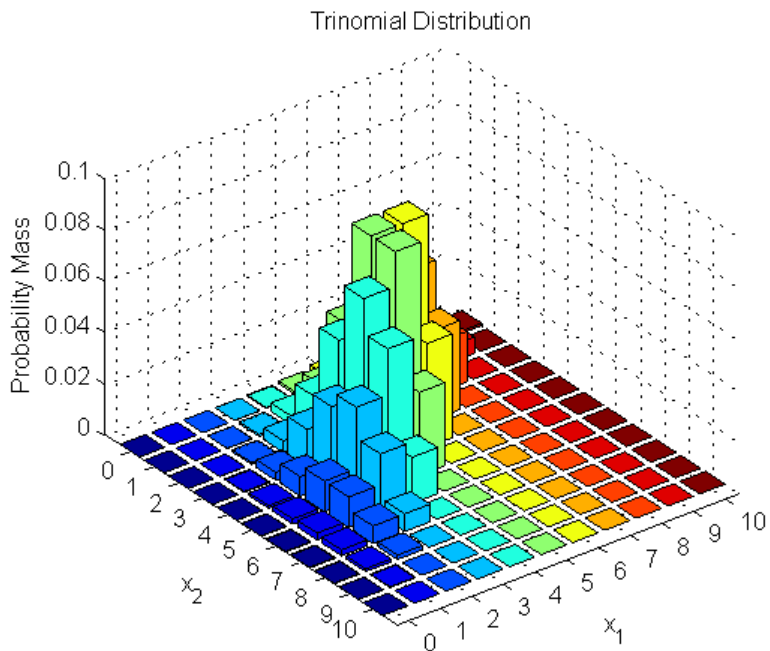
The expected value of outcome i is np_i . The variance of outcome i is $np_i(1-p_i)$. The covariance of outcomes i and j is $-np_i p_j$ for distinct i and j .

Example

The following uses `mnpdf` to produce a visualization of a trinomial distribution:

```
% Compute the distribution
p = [1/2 1/3 1/6]; % Outcome probabilities
n = 10; % Sample size
x1 = 0:n;
x2 = 0:n;
[X1,X2] = meshgrid(x1,x2);
X3 = n-(X1+X2);
Y = mnpdf([X1(:),X2(:),X3(:)], repmat(p, (n+1)^2, 1));

% Plot the distribution
Y = reshape(Y,n+1,n+1);
bar3(Y)
set(gca, 'XTickLabel', 0:n)
set(gca, 'YTickLabel', 0:n)
xlabel('x_1')
ylabel('x_2')
zlabel('Probability Mass')
```



Note that the visualization does not show x_3 , which is determined by the constraint $x_1 + x_2 + x_3 = n$.

See Also

“Discrete Distributions” on page 5-8

Multivariate Gaussian Distribution

See “Multivariate Normal Distribution” on page B-71.

Multivariate Normal Distribution

In this section...

“Definition” on page B-71

“Background” on page B-71

“Example” on page B-72

“See Also” on page B-76

Definition

The probability density function of the d -dimensional multivariate normal distribution is given by

$$y = f(x, \mu, \Sigma) = \frac{1}{\sqrt{|\Sigma|(2\pi)^d}} e^{-\frac{1}{2}(x-\mu) \Sigma^{-1}(x-\mu)'}$$

where x and μ are 1-by- d vectors and Σ is a d -by- d symmetric positive definite matrix. While it is possible to define the multivariate normal for singular Σ , the density cannot be written as above. Only random vector generation is supported for the singular case. Note that while most textbooks define the multivariate normal with x and μ oriented as column vectors, for the purposes of data analysis software, it is more convenient to orient them as row vectors, and Statistics Toolbox software uses that orientation.

Background

The multivariate normal distribution is a generalization of the univariate normal to two or more variables. It is a distribution for random vectors of correlated variables, each element of which has a univariate normal distribution. In the simplest case, there is no correlation among variables, and elements of the vectors are independent univariate normal random variables.

The multivariate normal distribution is parameterized with a mean vector, μ , and a covariance matrix, Σ . These are analogous to the mean μ and variance σ^2 parameters of a univariate normal distribution. The diagonal elements of Σ

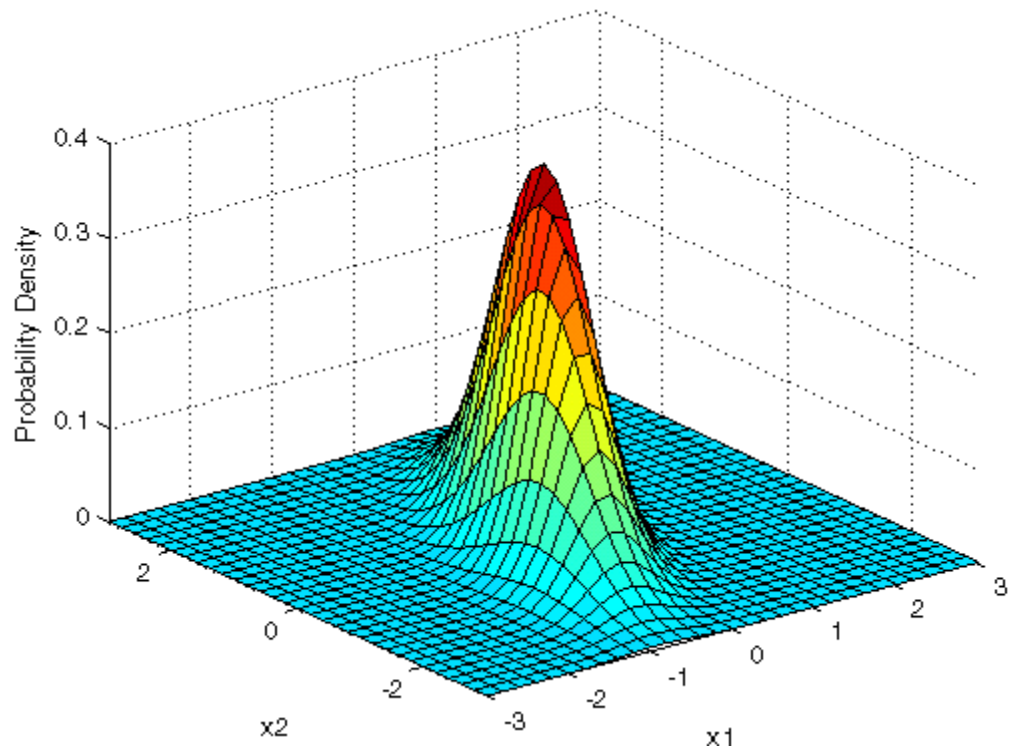
contain the variances for each variable, while the off-diagonal elements of Σ contain the covariances between variables.

The multivariate normal distribution is often used as a model for multivariate data, primarily because it is one of the few multivariate distributions that is tractable to work with.

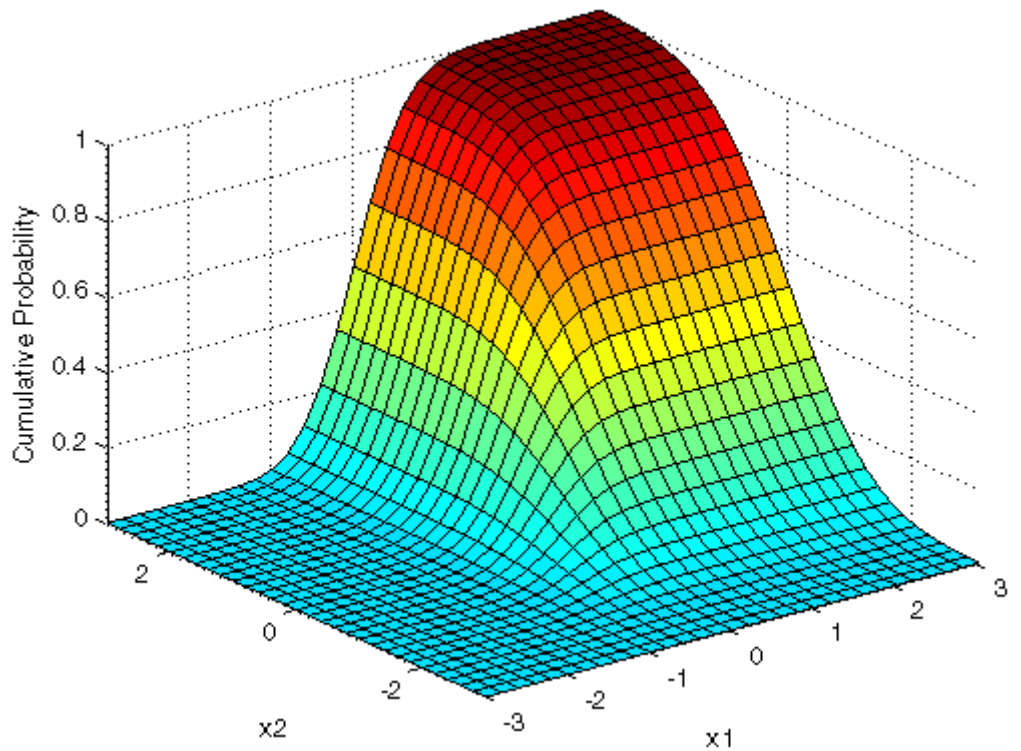
Example

This example shows the probability density function (pdf) and cumulative distribution function (cdf) for a bivariate normal distribution with unequal standard deviations. You can use the multivariate normal distribution in a higher number of dimensions as well, although visualization is not easy.

```
mu = [0 0];
Sigma = [.25 .3; .3 1];
x1 = -3:.2:3; x2 = -3:.2:3;
[X1,X2] = meshgrid(x1,x2);
F = mvnpdf([X1(:) X2(:)],mu,Sigma);
F = reshape(F,length(x2),length(x1));
surf(x1,x2,F);
caxis([min(F(:))-.5*range(F(:)),max(F(:))]);
axis([-3 3 -3 3 0 .4])
xlabel('x1'); ylabel('x2'); zlabel('Probability Density');
```

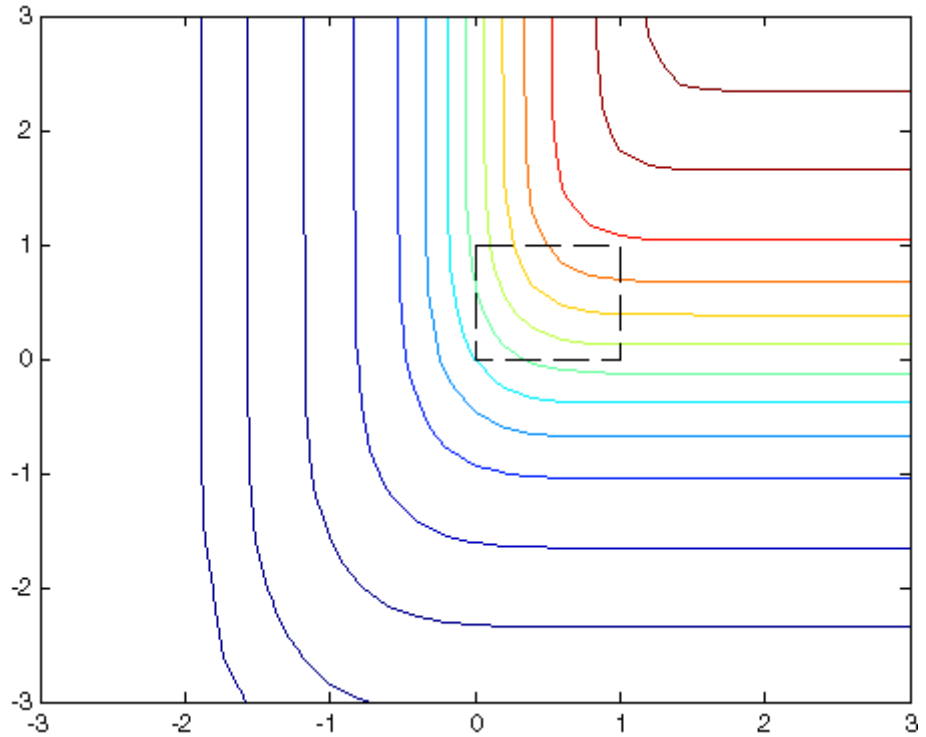



```
F = mvncdf([X1(:) X2(:)],mu,Sigma);  
F = reshape(F,length(x2),length(x1));  
surf(x1,x2,F);  
caxis([min(F(:))-.5*range(F(:)),max(F(:))]);  
axis([-3 3 -3 3 0 1])  
xlabel('x1'); ylabel('x2'); zlabel('Cumulative Probability');
```



Since the bivariate normal distribution is defined on the plane, you can also compute cumulative probabilities over rectangular regions. For example, this contour plot illustrates the computation that follows, of the probability contained within the unit square.

```
contour(x1,x2,F,[.0001 .001 .01 .05:.1:.95 .99 .999 .9999]);
xlabel('x'); ylabel('y');
line([0 0 1 1 0],[1 0 0 1 1],'linestyle','--','color','k');
```



```
mvncdf([0 0],[1 1],mu,Sigma)
ans =
    0.20974
```

Computing a multivariate cumulative probability requires significantly more work than computing a univariate probability. By default, the `mvncdf` function computes values to less than full machine precision, and returns an estimate of the error as an optional second output:

```
[F,err] = mvncdf([0 0],[1 1],mu,Sigma)
F =
    0.20974
err =
    1e-008
```

See Also

“Multivariate Distributions” on page 5-9

Multivariate t Distribution

In this section...

“Definition” on page B-77

“Background” on page B-77

“Example” on page B-78

“See Also” on page B-82

Definition

The probability density function of the d -dimensional multivariate Student’s t distribution is given by

$$f(x, \Sigma, \nu) = \frac{1}{|\Sigma|^{1/2}} \frac{1}{\sqrt{(\nu\pi)^d}} \frac{\Gamma((\nu + d) / 2)}{\Gamma(\nu / 2)} \left(1 + \frac{x' \Sigma^{-1} x}{\nu} \right)^{-(\nu+d)/2}.$$

where x is a 1-by- d vector, Σ is a d -by- d symmetric, positive definite matrix, and ν is a positive scalar. While it is possible to define the multivariate Student’s t for singular Σ , the density cannot be written as above. For the singular case, only random number generation is supported. Note that while most textbooks define the multivariate Student’s t with x oriented as a column vector, for the purposes of data analysis software, it is more convenient to orient x as a row vector, and Statistics Toolbox software uses that orientation.

Background

The multivariate Student’s t distribution is a generalization of the univariate Student’s t to two or more variables. It is a distribution for random vectors of correlated variables, each element of which has a univariate Student’s t distribution. In the same way as the univariate Student’s t distribution can be constructed by dividing a standard univariate normal random variable by the square root of a univariate chi-square random variable, the multivariate Student’s t distribution can be constructed by dividing a multivariate normal random vector having zero mean and unit variances by a univariate chi-square random variable.

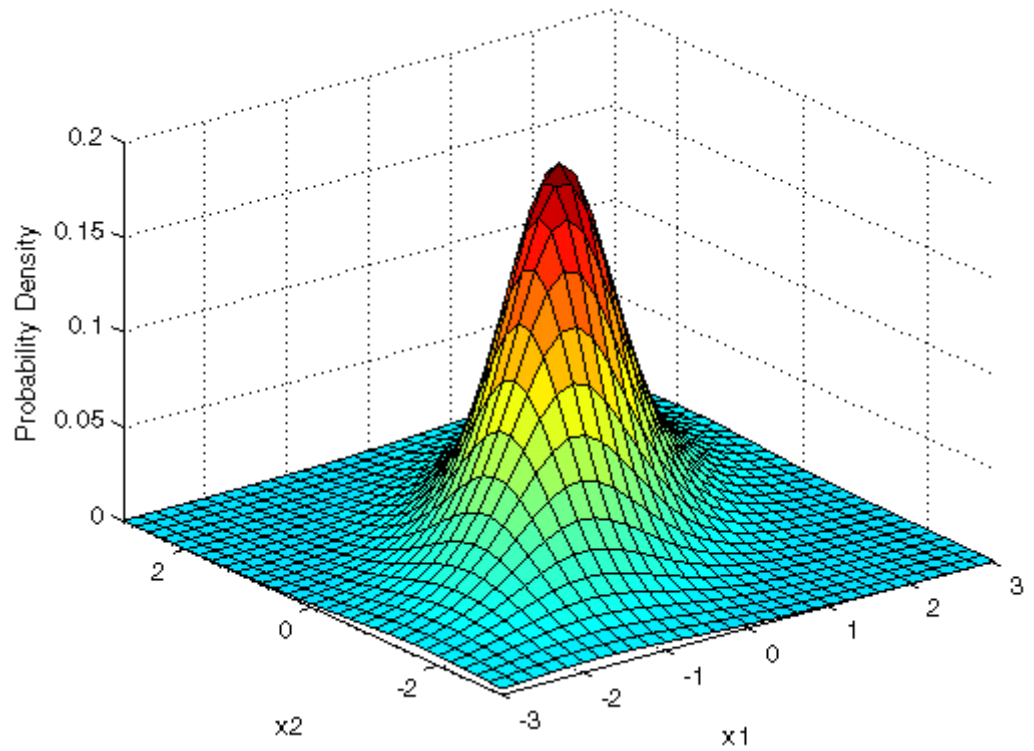
The multivariate Student's t distribution is parameterized with a correlation matrix, Σ , and a positive scalar degrees of freedom parameter, ν . ν is analogous to the degrees of freedom parameter of a univariate Student's t distribution. The off-diagonal elements of Σ contain the correlations between variables. Note that when Σ is the identity matrix, variables are uncorrelated; however, they are not independent.

The multivariate Student's t distribution is often used as a substitute for the multivariate normal distribution in situations where it is known that the marginal distributions of the individual variables have fatter tails than the normal.

Example

This example shows the probability density function (pdf) and cumulative distribution function (cdf) for a bivariate Student's t distribution. You can use the multivariate Student's t distribution in a higher number of dimensions as well, although visualization is not easy.

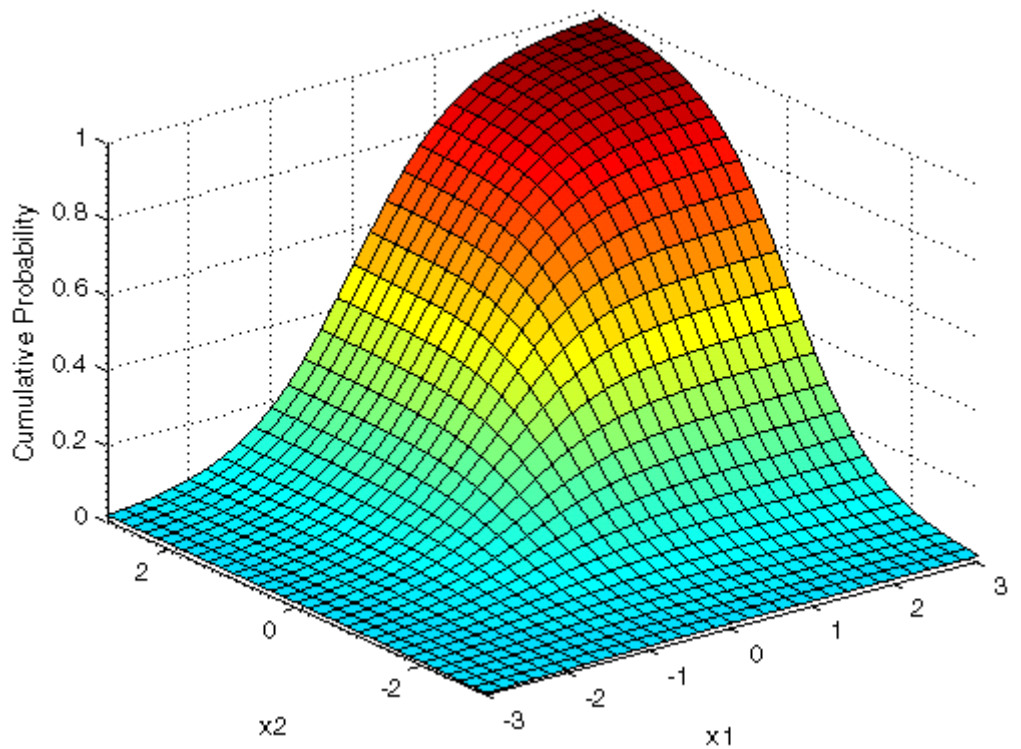
```
Rho = [1 .6; .6 1];
nu = 5;
x1 = -3:.2:3; x2 = -3:.2:3;
[X1,X2] = meshgrid(x1,x2);
F = mvtpdf([X1(:) X2(:)],Rho,nu);
F = reshape(F,length(x2),length(x1));
surf(x1,x2,F);
caxis([min(F(:))-.5*range(F(:)),max(F(:))]);
axis([-3 3 -3 3 0 .2])
xlabel('x1'); ylabel('x2'); zlabel('Probability Density');
```



```

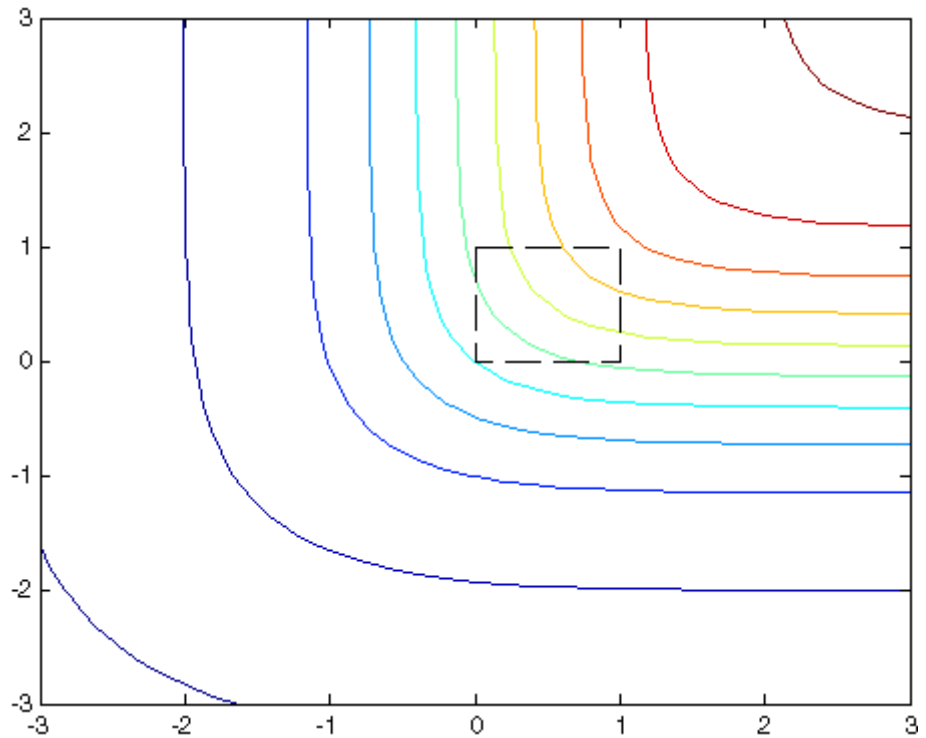
F = mvtcdf([X1(:) X2(:)],Rho,nu);
F = reshape(F,length(x2),length(x1));
surf(x1,x2,F);
caxis([min(F(:))-.5*range(F(:)),max(F(:))]);
axis([-3 3 -3 3 0 1])
xlabel('x1'); ylabel('x2'); zlabel('Cumulative Probability');

```



Since the bivariate Student's t distribution is defined on the plane, you can also compute cumulative probabilities over rectangular regions. For example, this contour plot illustrates the computation that follows, of the probability contained within the unit square.

```
contour(x1,x2,F,[.0001 .001 .01 .05:.1:.95 .99 .999 .9999]);
xlabel('x'); ylabel('y');
line([0 0 1 1 0],[1 0 0 1 1],'linestyle','--','color','k');
```

```
mvtcdf([0 0],[1 1],Rho,nu)
ans =
    0.14013
```

Computing a multivariate cumulative probability requires significantly more work than computing a univariate probability. By default, the `mvtcdf` function computes values to less than full machine precision, and returns an estimate of the error as an optional second output:

```
[F,err] = mvtcdf([0 0],[1 1],Rho,nu)
F =
    0.14013
err =
    1e-008
```

See Also

“Multivariate Distributions” on page 5-9

Nakagami Distribution

In this section...

“Definition” on page B-83

“Background” on page B-83

“Parameters” on page B-83

“See Also” on page B-84

Definition

The Nakagami distribution has the density function

$$2\left(\frac{\mu}{\omega}\right)^{\mu} \frac{1}{\Gamma(\mu)} x^{(2\mu-1)} e^{-\frac{\mu}{\omega}x^2}$$

with shape parameter μ and scale parameter $\omega > 0$, for $x > 0$. If x has a Nakagami distribution with parameters μ and ω , then x^2 has a gamma distribution with shape parameter μ and scale parameter ω/μ .

Background

In communications theory, Nakagami distributions, Rician distributions, and Rayleigh distributions are used to model scattered signals that reach a receiver by multiple paths. Depending on the density of the scatter, the signal will display different fading characteristics. Rayleigh and Nakagami distributions are used to model dense scatters, while Rician distributions model fading with a stronger line-of-sight. Nakagami distributions can be reduced to Rayleigh distributions, but give more control over the extent of the fading.

Parameters

See `mle`, `dfittool`.

See Also

“Continuous Distributions (Data)” on page 5-4

Negative Binomial Distribution

In this section...

“Definition” on page B-85

“Background” on page B-85

“Parameters” on page B-86

“Example” on page B-87

“See Also” on page B-88

Definition

When the r parameter is an integer, the negative binomial pdf is

$$y = f(x | r, p) = \binom{r+x-1}{x} p^r q^x I_{(0,1,\dots)}(x)$$

where $q = 1 - p$. When r is not an integer, the binomial coefficient in the definition of the pdf is replaced by the equivalent expression

$$\frac{\Gamma(r+x)}{\Gamma(r)\Gamma(x+1)}$$

Background

In its simplest form (when r is an integer), the negative binomial distribution models the number of failures x before a specified number of successes is reached in a series of independent, identical trials. Its parameters are the probability of success in a single trial, p , and the number of successes, r . A special case of the negative binomial distribution, when $r = 1$, is the geometric distribution, which models the number of failures before the first success.

More generally, r can take on non-integer values. This form of the negative binomial distribution has no interpretation in terms of repeated trials, but, like the Poisson distribution, it is useful in modeling count data. The negative binomial distribution is more general than the Poisson distribution because it has a variance that is greater than its mean, making it suitable for count data

that do not meet the assumptions of the Poisson distribution. In the limit, as r increases to infinity, the negative binomial distribution approaches the Poisson distribution.

Parameters

Suppose you are collecting data on the number of auto accidents on a busy highway, and would like to be able to model the number of accidents per day. Because these are count data, and because there are a very large number of cars and a small probability of an accident for any specific car, you might think to use the Poisson distribution. However, the probability of having an accident is likely to vary from day to day as the weather and amount of traffic change, and so the assumptions needed for the Poisson distribution are not met. In particular, the variance of this type of count data sometimes exceeds the mean by a large amount. The data below exhibit this effect: most days have few or no accidents, and a few days have a large number.

```
accident = [2 3 4 2 3 1 12 8 14 31 23 1 10 7 0];
mean(accident)
ans =
    8.0667
```

```
var(accident)
ans =
    79.352
```

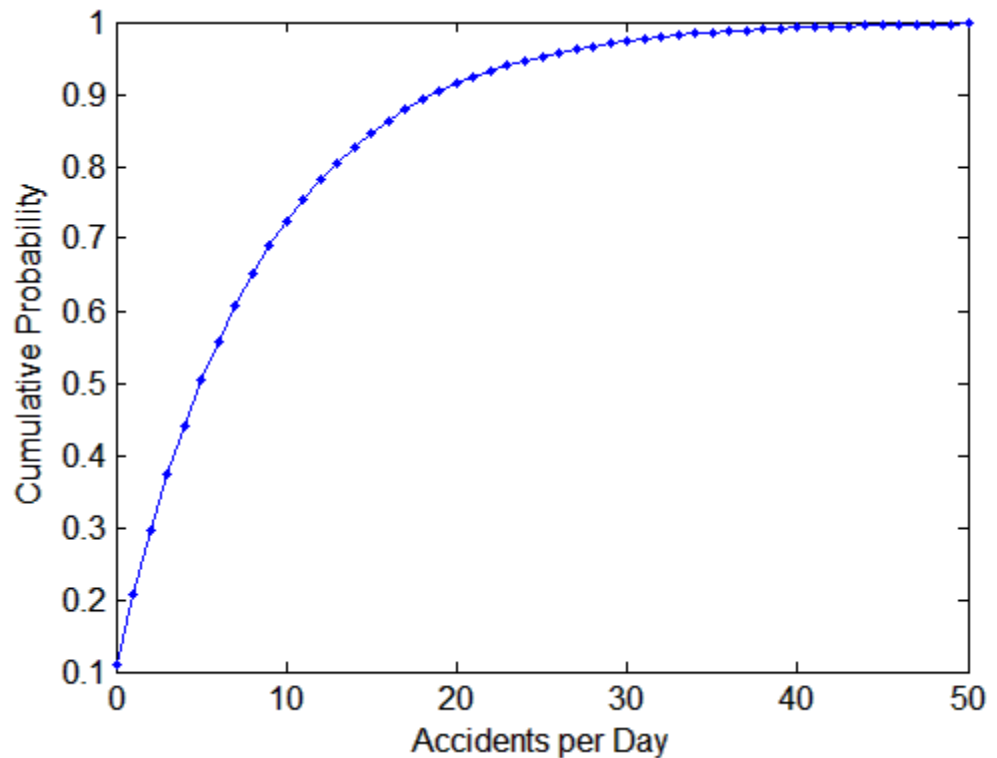
The negative binomial distribution is more general than the Poisson, and is often suitable for count data when the Poisson is not. The function `nbinfit` returns the maximum likelihood estimates (MLEs) and confidence intervals for the parameters of the negative binomial distribution. Here are the results from fitting the accident data:

```
[phat,pci] = nbinfit(accident)
phat =
    1.0060    0.1109
pci =
    0.2152    0.0171
    1.7968    0.2046
```

It is difficult to give a physical interpretation in this case to the individual parameters. However, the estimated parameters can be used in a model

for the number of daily accidents. For example, a plot of the estimated cumulative probability function shows that while there is an estimated 10% chance of no accidents on a given day, there is also about a 10% chance that there will be 20 or more accidents.

```
plot(0:50,nbincdf(0:50,phat(1),phat(2)),'.-');
xlabel('Accidents per Day')
ylabel('Cumulative Probability')
```

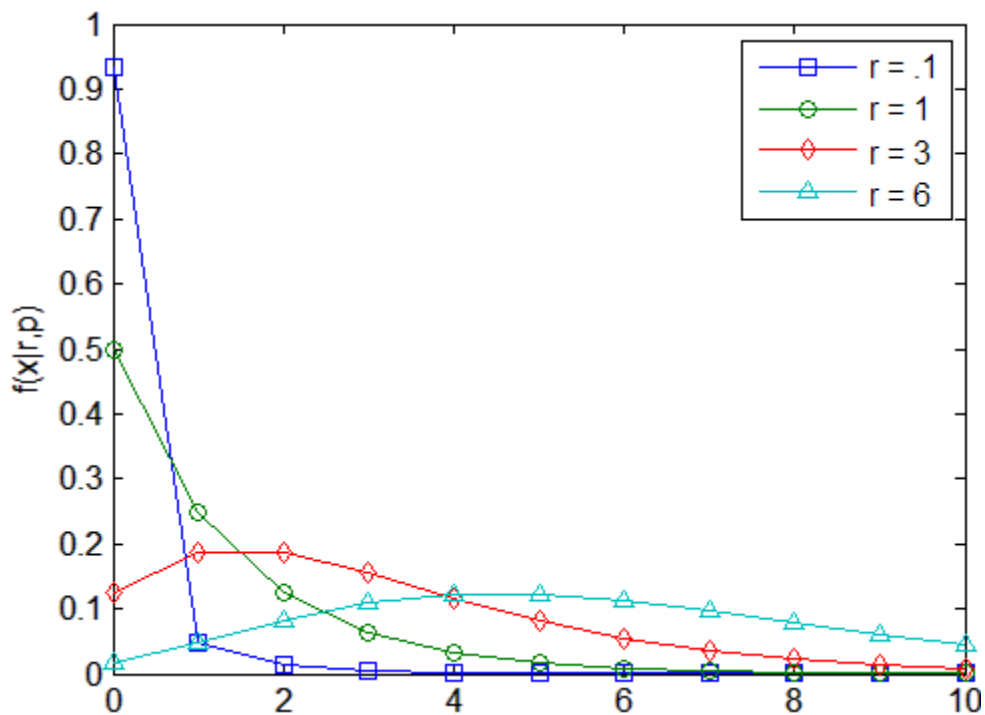


Example

The negative binomial distribution can take on a variety of shapes ranging from very skewed to nearly symmetric. This example plots the probability function for different values of r , the desired number of successes: .1, 1, 3, 6.

```
x = 0:10;
```

```
plot(x,nbinpdf(x,.1,.5),'s-', ...  
     x,nbinpdf(x,1,.5),'o-', ...  
     x,nbinpdf(x,3,.5),'d-', ...  
     x,nbinpdf(x,6,.5),'^-',);  
legend({'r = .1' 'r = 1' 'r = 3' 'r = 6'})  
xlabel('x')  
ylabel('f(x|r,p)')
```



See Also

“Discrete Distributions” on page 5-8

Noncentral Chi-Square Distribution

In this section...

“Definition” on page B-89

“Background” on page B-89

“Example” on page B-90

“See Also” on page B-90

Definition

There are many equivalent formulas for the noncentral chi-square distribution function. One formulation uses a modified Bessel function of the first kind. Another uses the generalized Laguerre polynomials. The cumulative distribution function is computed using a weighted sum of χ^2 probabilities with the weights equal to the probabilities of a Poisson distribution. The Poisson parameter is one-half of the noncentrality parameter of the noncentral chi-square

$$F(x | \nu, \delta) = \sum_{j=0}^{\infty} \left(\frac{\left(\frac{1}{2}\delta\right)^j}{j!} e^{-\frac{\delta}{2}} \right) \Pr[\chi_{\nu+2j}^2 \leq x]$$

where δ is the noncentrality parameter.

Background

The χ^2 distribution is actually a simple special case of the noncentral chi-square distribution. One way to generate random numbers with a χ^2 distribution (with ν degrees of freedom) is to sum the squares of ν standard normal random numbers (mean equal to zero.)

What if the normally distributed quantities have a mean other than zero? The sum of squares of these numbers yields the noncentral chi-square distribution. The noncentral chi-square distribution requires two parameters: the degrees

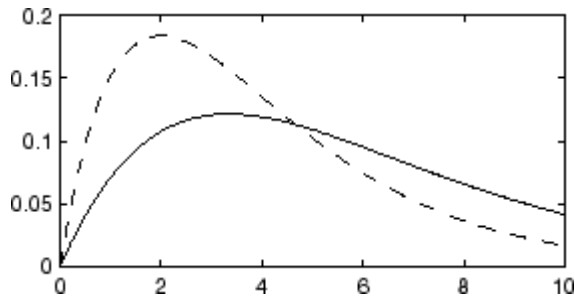
of freedom and the noncentrality parameter. The noncentrality parameter is the sum of the squared means of the normally distributed quantities.

The noncentral chi-square has scientific application in thermodynamics and signal processing. The literature in these areas may refer to it as the “Rician Distribution” on page B-106 or generalized “Rayleigh Distribution” on page B-104.

Example

The following commands generate a plot of the noncentral chi-square pdf.

```
x = (0:0.1:10)';  
p1 = ncx2pdf(x,4,2);  
p = chi2pdf(x,4);  
plot(x,p,'-',x,p1,'-')
```



See Also

“Continuous Distributions (Statistics)” on page 5-7

Noncentral F Distribution

In this section...

“Definition” on page B-91

“Background” on page B-91

“Example” on page B-92

“See Also” on page B-92

Definition

Similar to the noncentral χ^2 distribution, the toolbox calculates noncentral F distribution probabilities as a weighted sum of incomplete beta functions using Poisson probabilities as the weights.

$$F(x | v_1, v_2, \delta) = \sum_{j=0}^{\infty} \left(\frac{\left(\frac{1}{2}\delta\right)^j}{j!} e^{-\frac{\delta}{2}} \right) I\left(\frac{v_1 \cdot x}{v_2 + v_1 \cdot x} \middle| \frac{v_1}{2} + j, \frac{v_2}{2}\right)$$

$I(x | a, b)$ is the incomplete beta function with parameters a and b , and δ is the noncentrality parameter.

Background

As with the χ^2 distribution, the F distribution is a special case of the noncentral F distribution. The F distribution is the result of taking the ratio of χ^2 random variables each divided by its degrees of freedom.

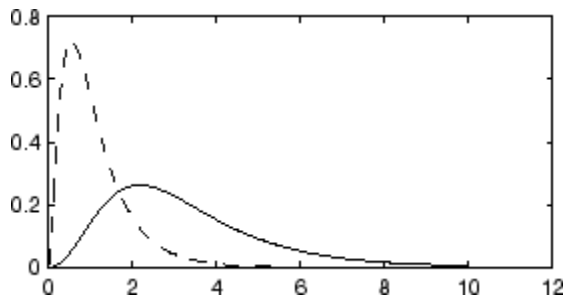
If the numerator of the ratio is a noncentral chi-square random variable divided by its degrees of freedom, the resulting distribution is the noncentral F distribution.

The main application of the noncentral F distribution is to calculate the power of a hypothesis test relative to a particular alternative.

Example

The following commands generate a plot of the noncentral F pdf.

```
x = (0.01:0.1:10.01)';  
p1 = ncfpdf(x,5,20,10);  
p = fpdf(x,5,20);  
plot(x,p,'-',x,p1,'-')
```



See Also

“Continuous Distributions (Statistics)” on page 5-7

Noncentral t Distribution

In this section...

“Definition” on page B-93

“Background” on page B-93

“Example” on page B-94

“See Also” on page B-94

Definition

The most general representation of the noncentral t distribution is quite complicated. Johnson and Kotz [60] give a formula for the probability that a noncentral t variate falls in the range $[-u, u]$.

$$P(-u < x < u \mid \nu, \delta) = \sum_{j=0}^{\infty} \left(\frac{\left(\frac{1}{2}\delta^2\right)^j}{j!} e^{-\frac{\delta^2}{2}} \right) I\left(\frac{u^2}{\nu + u^2} \mid \frac{1}{2} + j, \frac{\nu}{2}\right)$$

$I(x \mid \nu, \delta)$ is the incomplete beta function with parameters ν and δ . δ is the noncentrality parameter, and ν is the number of degrees of freedom.

Background

The noncentral t distribution is a generalization of Student's t distribution.

Student's t distribution with $n - 1$ degrees of freedom models the t -statistic

$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}}$$

where \bar{x} is the sample mean and s is the sample standard deviation of a random sample of size n from a normal population with mean μ . If the population mean is actually μ_0 , then the t -statistic has a noncentral t distribution with noncentrality parameter

$$\delta = \frac{\mu_0 - \mu}{\sigma / \sqrt{n}}$$

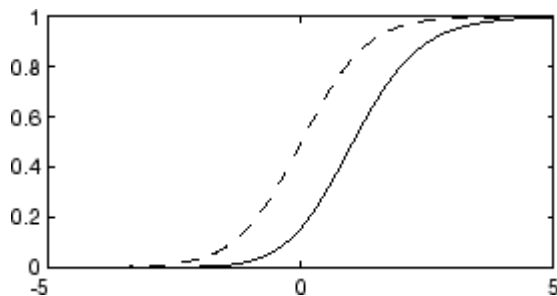
The noncentrality parameter is the normalized difference between μ_0 and μ .

The noncentral t distribution gives the probability that a t test will correctly reject a false null hypothesis of mean μ when the population mean is actually μ_0 ; that is, it gives the power of the t test. The power increases as the difference $\mu_0 - \mu$ increases, and also as the sample size n increases.

Example

The following commands generate a plot of the noncentral t pdf.

```
x = (-5:0.1:5)';  
p1 = nctcdf(x,10,1);  
p = tcdf(x,10);  
plot(x,p,'-',x,p1,'-')
```



See Also

“Continuous Distributions (Statistics)” on page 5-7

Nonparametric Distributions

See the discussion of `ksdensity` in “Estimating PDFs without Parameters” on page 5-56.

Normal Distribution

In this section...
“Definition” on page B-96
“Background” on page B-96
“Parameters” on page B-97
“Example” on page B-98
“See Also” on page B-98

Definition

The normal pdf is

$$y = f(x | \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Background

The normal distribution is a two-parameter family of curves. The first parameter, μ , is the mean. The second, σ , is the standard deviation. The standard normal distribution (written $\Phi(x)$) sets μ to 0 and σ to 1.

$\Phi(x)$ is functionally related to the error function, *erf*.

$$\text{erf}(x) = 2\Phi(x\sqrt{2}) - 1$$

The first use of the normal distribution was as a continuous approximation to the binomial.

The usual justification for using the normal distribution for modeling is the Central Limit Theorem, which states (roughly) that the sum of independent samples from any distribution with finite mean and variance converges to the normal distribution as the sample size goes to infinity.

Parameters

To use statistical parameters such as mean and standard deviation reliably, you need to have a good estimator for them. The maximum likelihood estimates (MLEs) provide one such estimator. However, an MLE might be biased, which means that its expected value of the parameter might not equal the parameter being estimated. For example, an MLE is biased for estimating the variance of a normal distribution. An unbiased estimator that is commonly used to estimate the parameters of the normal distribution is the *minimum variance unbiased estimator (MVUE)*. The MVUE has the minimum variance of all unbiased estimators of a parameter.

The MVUEs of parameters μ and σ^2 for the normal distribution are the sample mean and variance. The sample mean is also the MLE for μ . The following are two common formulas for the variance.

$$s^2 = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^2 \quad (\text{B-1})$$

$$s^2 = \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2 \quad (\text{B-2})$$

where

$$\bar{x} = \sum_{i=1}^n \frac{x_i}{n}$$

Equation 1 is the maximum likelihood estimator for σ^2 , and equation 2 is the MVUE.

As an example, suppose you want to estimate the mean, μ , and the variance, σ^2 , of the heights of all fourth grade children in the United States. The function `normfit` returns the MVUE for μ , the square root of the MVUE for σ^2 , and confidence intervals for μ and σ^2 . Here is a playful example modeling the heights in inches of a randomly chosen fourth grade class.

```
height = normrnd(50,2,30,1);           % Simulate heights.
[mu,s,muci,sci] = normfit(height)
```

```
mu =  
 50.2025
```

```
s =  
 1.7946
```

```
muci =  
 49.5210  
 50.8841
```

```
sci =  
 1.4292  
 2.4125
```

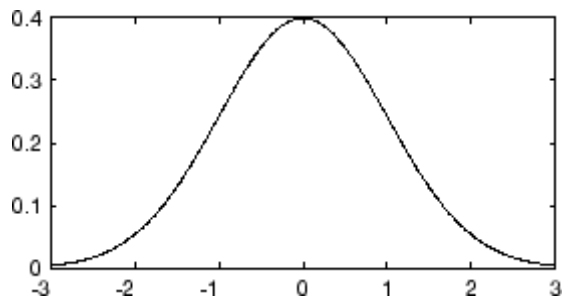
Note that s^2 is the MVUE of the variance.

```
s^2
```

```
ans =  
 3.2206
```

Example

The plot shows the bell curve of the standard normal pdf, with $\mu = 0$ and $\sigma = 1$.



See Also

“Continuous Distributions (Data)” on page 5-4

Pareto Distribution

See “Generalized Pareto Distribution” on page B-50.

Pearson System

See “Pearson and Johnson Systems” on page 6-25.

Piecewise Distributions

See the discussion of the `@piecewisedistribution` class in “Fitting Piecewise Distributions” on page 5-73.

Poisson Distribution

In this section...
“Definition” on page B-102
“Background” on page B-102
“Parameters” on page B-103
“Example” on page B-103
“See Also” on page B-103

Definition

The Poisson pdf is

$$y = f(x | \lambda) = \frac{\lambda^x}{x!} e^{-\lambda} I_{(0,1,\dots)}(x)$$

Background

The Poisson distribution is appropriate for applications that involve counting the number of times a random event occurs in a given amount of time, distance, area, etc. Sample applications that involve Poisson distributions include the number of Geiger counter clicks per second, the number of people walking into a store in an hour, and the number of flaws per 1000 feet of video tape.

The Poisson distribution is a one-parameter discrete distribution that takes nonnegative integer values. The parameter, λ , is both the mean and the variance of the distribution. Thus, as the size of the numbers in a particular sample of Poisson random numbers gets larger, so does the variability of the numbers.

The Poisson distribution is the limiting case of a binomial distribution where N approaches infinity and p goes to zero while $Np = \lambda$.

The Poisson and exponential distributions are related. If the number of counts follows the Poisson distribution, then the interval between individual counts follows the exponential distribution.

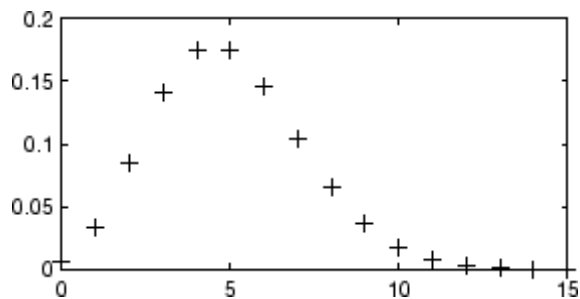
Parameters

The MLE and the MVUE of the Poisson parameter, λ , is the sample mean. The sum of independent Poisson random variables is also Poisson distributed with the parameter equal to the sum of the individual parameters. This is used to calculate confidence intervals λ . As λ gets large the Poisson distribution can be approximated by a normal distribution with $\mu = \lambda$ and $\sigma^2 = \lambda$. This approximation is used to calculate confidence intervals for values of λ greater than 100.

Example

The plot shows the probability for each nonnegative integer when $\lambda = 5$.

```
x = 0:15;  
y = poisspdf(x,5);  
plot(x,y, '+' )
```



See Also

“Discrete Distributions” on page 5-8

Rayleigh Distribution

In this section...
“Definition” on page B-104
“Background” on page B-104
“Parameters” on page B-105
“Example” on page B-105
“See Also” on page B-105

Definition

The Rayleigh pdf is

$$y = f(x | b) = \frac{x}{b^2} e^{\left(\frac{-x^2}{2b^2}\right)}$$

Background

The Rayleigh distribution is a special case of the Weibull distribution. If A and B are the parameters of the Weibull distribution, then the Rayleigh distribution with parameter b is equivalent to the Weibull distribution with parameters $A = \sqrt{2}b$ and $B = 2$.

If the component velocities of a particle in the x and y directions are two independent normal random variables with zero means and equal variances, then the distance the particle travels per unit time is distributed Rayleigh.

In communications theory, Nakagami distributions, Rician distributions, and Rayleigh distributions are used to model scattered signals that reach a receiver by multiple paths. Depending on the density of the scatter, the signal will display different fading characteristics. Rayleigh and Nakagami distributions are used to model dense scatters, while Rician distributions model fading with a stronger line-of-sight. Nakagami distributions can be reduced to Rayleigh distributions, but give more control over the extent of the fading.

Parameters

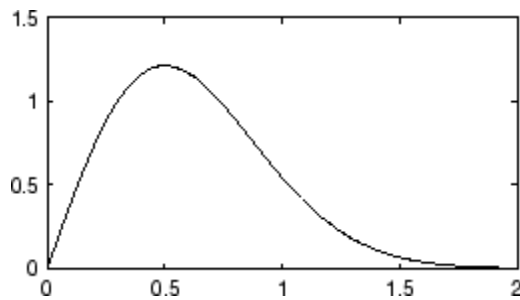
The `raylfit` function returns the MLE of the Rayleigh parameter. This estimate is

$$b = \sqrt{\frac{1}{2n} \sum_{i=1}^n x_i^2}$$

Example

The following commands generate a plot of the Rayleigh pdf.

```
x = [0:0.01:2];  
p = raylpdf(x,0.5);  
plot(x,p)
```



See Also

“Continuous Distributions (Data)” on page 5-4

Rician Distribution

In this section...

“Definition” on page B-106

“Background” on page B-106

“Parameters” on page B-106

“See Also” on page B-107

Definition

The Rician distribution has the density function

$$I_0\left(\frac{xs}{\sigma^2}\right)\frac{x}{\sigma^2}e^{-\left(\frac{x^2+s^2}{2\sigma^2}\right)}$$

with noncentrality parameter $s \geq 0$ and scale parameter $\sigma > 0$, for $x > 0$. I_0 is the zero-order modified Bessel function of the first kind. If x has a Rician distribution with parameters s and σ , then $(x/\sigma)^2$ has a noncentral chi-square distribution with two degrees of freedom and noncentrality parameter $(s/\sigma)^2$.

Background

In communications theory, Nakagami distributions, Rician distributions, and Rayleigh distributions are used to model scattered signals that reach a receiver by multiple paths. Depending on the density of the scatter, the signal will display different fading characteristics. Rayleigh and Nakagami distributions are used to model dense scatters, while Rician distributions model fading with a stronger line-of-sight. Nakagami distributions can be reduced to Rayleigh distributions, but give more control over the extent of the fading.

Parameters

See `mle`, `dfittool`.

See Also

“Continuous Distributions (Data)” on page 5-4

Student's t Distribution

In this section...

“Definition” on page B-108

“Background” on page B-108

“Example” on page B-109

“See Also” on page B-109

Definition

Student's t pdf is

$$y = f(x | \nu) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right)} \frac{1}{\sqrt{\nu\pi}} \frac{1}{\left(1 + \frac{x^2}{\nu}\right)^{\frac{\nu+1}{2}}}$$

where $\Gamma(\cdot)$ is the Gamma function.

Background

The t distribution is a family of curves depending on a single parameter ν (the degrees of freedom). As ν goes to infinity, the t distribution approaches the standard normal distribution.

W. S. Gossett discovered the distribution through his work at the Guinness brewery. At the time, Guinness did not allow its staff to publish, so Gossett used the pseudonym “Student.”

If x is a random sample of size n from a normal distribution with mean μ , then the statistic

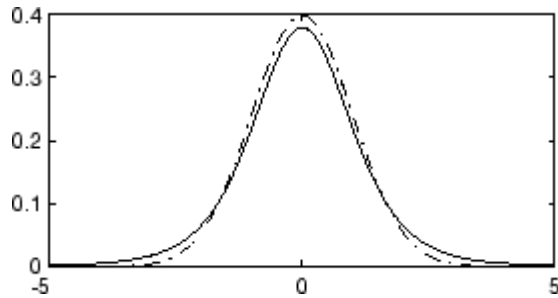
$$t = \frac{\bar{x} - \mu}{s/\sqrt{n}}$$

where \bar{x} is the sample mean and s is the sample standard deviation, has Student's t distribution with $n - 1$ degrees of freedom.

Example

The plot compares the t distribution with $\nu = 5$ (solid line) to the shorter tailed, standard normal distribution (dashed line).

```
x = -5:0.1:5;  
y = tpdf(x,5);  
z = normpdf(x,0,1);  
plot(x,y,'-',x,z,'-.-')
```



See Also

“Continuous Distributions (Statistics)” on page 5-7

t Location-Scale Distribution

In this section...

“Definition” on page B-110

“Background” on page B-110

“Parameters” on page B-110

“See Also” on page B-111

Definition

The t location-scale distribution has the density function

$$\frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sigma\sqrt{\nu\pi}\Gamma\left(\frac{\nu}{2}\right)} \left[\frac{\nu + \left(\frac{x-\mu}{\sigma}\right)^2}{\nu} \right]^{-\left(\frac{\nu+1}{2}\right)}$$

with location parameter μ , scale parameter $\sigma > 0$, and shape parameter $\nu > 0$. If x has a t location-scale distribution, with parameters μ , σ , and ν , then

$$\frac{x - \mu}{\sigma}$$

has a Student’s t distribution with ν degrees of freedom.

Background

The t location-scale distribution is useful for modeling data distributions with heavier tails (more prone to outliers) than the normal distribution. It approaches the normal distribution as ν approaches infinity, and smaller values of ν yield heavier tails.

Parameters

See `mle`, `dfittool`.

See Also

“Continuous Distributions (Statistics)” on page 5-7

Uniform Distribution (Continuous)

In this section...
“Definition” on page B-112
“Background” on page B-112
“Parameters” on page B-112
“Example” on page B-112
“See Also” on page B-113

Definition

The uniform cdf is

$$p = F(x | a, b) = \frac{x - a}{b - a} I_{[a, b]}(x)$$

Background

The uniform distribution (also called rectangular) has a constant pdf between its two parameters a (the minimum) and b (the maximum). The standard uniform distribution ($a = 0$ and $b = 1$) is a special case of the beta distribution, obtained by setting both of its parameters to 1.

The uniform distribution is appropriate for representing the distribution of round-off errors in values tabulated to a particular number of decimal places.

Parameters

The sample minimum and maximum are the MLEs of a and b respectively.

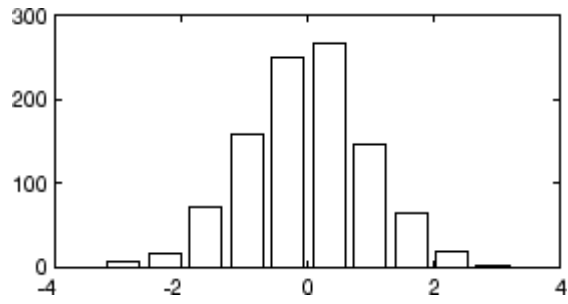
Example

The example illustrates the inversion method for generating normal random numbers using `rand` and `norminv`. Note that the MATLAB function, `randn`, does not use inversion since it is not efficient for this case.

```
u = rand(1000,1);
```



```
x = norminv(u,0,1);  
hist(x)
```



See Also

“Continuous Distributions (Data)” on page 5-4

Uniform Distribution (Discrete)

In this section...
“Definition” on page B-114
“Background” on page B-114
“Example” on page B-114
“See Also” on page B-115

Definition

The discrete uniform pdf is

$$y = f(x | N) = \frac{1}{N} I_{(1, \dots, N)}(x)$$

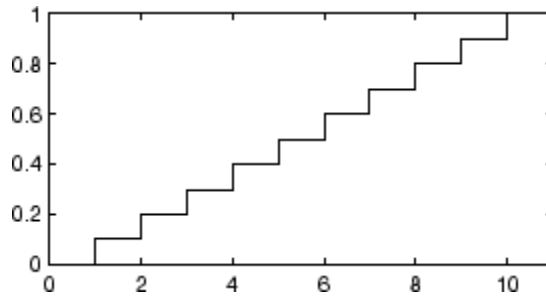
Background

The discrete uniform distribution is a simple distribution that puts equal weight on the integers from one to N .

Example

As for all discrete distributions, the cdf is a step function. The plot shows the discrete uniform cdf for $N = 10$.

```
x = 0:10;  
y = unidcdf(x,10);  
stairs(x,y)  
set(gca, 'Xlim', [0 11])
```



Pick a random sample of 10 from a list of 553 items:

```
numbers = unidrnd(553,1,10)
numbers =
    293    372     5    213    37    231    380    326    515    468
```

See Also

“Discrete Distributions” on page 5-8

Weibull Distribution

In this section...
“Definition” on page B-116
“Background” on page B-116
“Parameters” on page B-117
“Example” on page B-117
“See Also” on page B-118

Definition

The Weibull pdf is positive only for positive values of x , and is zero otherwise. For strictly positive values of the shape parameter b and scale parameter a , the density is

$$f(x | a, b) = \frac{b}{a} \left(\frac{x}{a}\right)^{b-1} e^{-(x/a)^b}.$$

Background

Waloddi Weibull offered the distribution that bears his name as an appropriate analytical tool for modeling the breaking strength of materials. Current usage also includes reliability and lifetime modeling. The Weibull distribution is more flexible than the exponential for these purposes.

To see why, consider the hazard rate function (instantaneous failure rate). If $f(t)$ and $F(t)$ are the pdf and cdf of a distribution, then the hazard rate is

$$h(t) = \frac{f(t)}{1 - F(t)}$$

Substituting the pdf and cdf of the exponential distribution for $f(t)$ and $F(t)$ above yields a constant. The example below shows that the hazard rate for the Weibull distribution can vary.

Parameters

Suppose you want to model the tensile strength of a thin filament using the Weibull distribution. The function `wblfit` gives maximum likelihood estimates and confidence intervals for the Weibull parameters.

```
strength = wblrnd(0.5,2,100,1);           % Simulated strengths.
[p,ci] = wblfit(strength)
```

```
p =
0.4715    1.9811
```

```
ci =

    0.4248    1.7067
    0.5233    2.2996
```

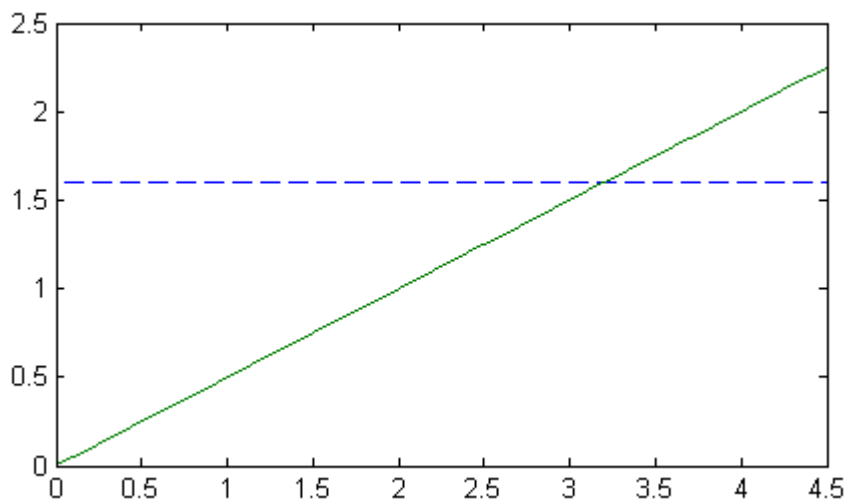
The default 95% confidence interval for each parameter contains the true value.

Example

The exponential distribution has a constant hazard function, which is not generally the case for the Weibull distribution.

The plot shows the hazard functions for exponential (dashed line) and Weibull (solid line) distributions having the same mean life. The Weibull hazard rate here increases with age (a reasonable assumption).

```
t = 0:0.1:4.5;
h1 = exppdf(t,0.6267) ./ (1-expcdf(t,0.6267));
h2 = wblpdf(t,2,2) ./ (1-wblcdf(t,2,2));
plot(t,h1,'--',t,h2,'-')
```



See Also

“Continuous Distributions (Data)” on page 5-4

Wishart Distribution

In this section...

“Definition” on page B-119

“Background” on page B-119

“Example” on page B-120

“See Also” on page B-120

Definition

The probability density function of the d -dimensional Wishart distribution is given by

$$y = f(X, \Sigma, \nu) = \frac{|X|^{(\nu-d-1)/2} e^{\left(-\frac{1}{2}\text{trace}(\Sigma^{-1}X)\right)}}{2^{(\nu d)/2} \pi^{(d(d-1))/4} |\Sigma|^{\nu/2} \Gamma(\nu/2) \dots \Gamma(\nu-(d-1))/2}$$

where X and Σ are d -by- d symmetric positive definite matrices, and ν is a scalar greater than $d - 1$. While it is possible to define the Wishart for singular Σ , the density cannot be written as above.

Only random matrix generation is supported for the Wishart distribution, including both singular and nonsingular Σ .

Background

The Wishart distribution is a generalization of the univariate chi-square distribution to two or more variables. It is a distribution for symmetric positive semidefinite matrices, typically covariance matrices, the diagonal elements of which are each chi-square random variables. In the same way as the chi-square distribution can be constructed by summing the squares of independent, identically distributed, zero-mean univariate normal random variables, the Wishart distribution can be constructed by summing the inner products of independent, identically distributed, zero-mean multivariate normal random vectors.

The Wishart distribution is parameterized with a symmetric, positive semidefinite matrix, Σ , and a positive scalar degrees of freedom parameter, v . v is analogous to the degrees of freedom parameter of a univariate chi-square distribution, and Σv is the mean of the distribution.

The Wishart distribution is often used as a model for the distribution of the sample covariance matrix for multivariate normal random data, after scaling by the sample size.

Example

If x is a bivariate normal random vector with mean zero and covariance matrix

$$\Sigma = \begin{pmatrix} 1 & .5 \\ .5 & 2 \end{pmatrix}$$

then you can use the Wishart distribution to generate a sample covariance matrix without explicitly generating x itself. Notice how the sampling variability is quite large when the degrees of freedom is small.

```
Sigma = [1 .5; .5 2];  
df = 10; S1 = wishrnd(Sigma,df)/df
```

```
S1 =  
    1.7959    0.64107  
    0.64107    1.5496
```

```
df = 1000; S2 = wishrnd(Sigma,df)/df
```

```
S2 =  
    0.9842    0.50158  
    0.50158    2.1682
```

See Also

“Inverse Wishart Distribution” on page B-59, “Multivariate Distributions” on page 5-9

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A

absolute deviation 3-5
 addedvarplot 20-2
 additive effects 8-9
 adjacent value 20-100
 adjacent values 4-7
 AIC. *See* Akaike Information Criterion
 Akaike Information Criterion (AIC) 5-106 20-15
 alternative hypotheses 7-3
 analysis of variance
 F distribution B-39
 functions 18-35
 multivariate 8-39
 N-way 8-12
 one-way 8-3
 two-way 8-9
 visualization functions 18-13 18-35
 andrewsplot 20-16
 anova1 20-24
 anova2 20-30
 anovan 20-34
 Ansari-Bradley test 7-13
 ansaribradley 20-44
 aoctool 8-27 20-47
 arrays
 categorical
 accessing 2-17
 combining 2-18
 computing with 2-20
 constructing 2-15
 implementation 2-15
 types 2-14
 dataset
 creating 2-22
 multidimensional 2-6
 numerical 2-4
 statistical 2-11
 average linkage 20-1182

B

bacteria counts 8-4
 Bartlett multiple-sample test 7-15
 Bartlett's test 7-13
 barttest 20-53
 batch updates 20-1072
 Bayes classification
 objects 18-49 19-8
 Bayes Information Criterion (BIC) 5-106 20-69
 bbdesign 20-54
 Bernoulli distribution B-3
 Bernoulli random variables 20-77
 beta distribution B-4
 betacdf 20-57
 betafit 20-58
 betainv 20-60
 betalike 20-62
 betapdf 20-64
 betarnd 20-66
 betastat 20-68
 BIC. *See* Bayes Information Criterion
 binocdf 20-70
 binofit 20-72
 binoinv 20-74
 binomial distribution B-7
 negative B-85
 binopdf 20-75
 binornd 20-77
 binostat 20-79
 biplot 20-80
 Birnbaum-Saunders distribution B-10
 bootci 20-83
 bootstrapping 3-16
 bootstrp 20-87
 box plots 4-6
 Box-Behnken designs 15-13
 generating 20-54
 Box-Wilson designs 15-9
 boxplot 20-94
 Burr Type XII distribution B-12

C

- candgen 20-113
- candidate sets 15-17
- canoncorr 20-117
- Canonical Maximum Likelihood (CML) 20-368
- capability 20-120
- capability studies 16-6
- capaplot 20-123
- case names
 - reading from file 20-125
 - writing to file 20-126
- caseread 20-125
- casewrite 20-126
- categorical arrays
 - accessing 2-17
 - combining 2-18
 - computing with 2-20
 - constructing 2-15
 - functions 18-3
 - implementation 2-15
 - objects 19-2
 - types 2-14
- categorical data 2-13
- CCD. *See* central composite designs
- ccdesign 20-138
- cdf 20-142
- cdfplot 20-149
- cell arrays
 - storing heterogeneous data in 2-7
- central composite designs (CCDs)
 - generating 20-138
 - types 15-9
- Central Limit Theorem B-96
- central tendency
 - functions 18-9
- centroid linkage 20-1182
- chi-square distribution B-25
- chi-square goodness-of-fit test 7-13
- chi-square variance test, one-sample 7-15
- chi2cdf 20-159
- chi2gof 20-160
- chi2inv 20-165
- chi2pdf 20-167
- chi2rnd 20-169
- chi2stat 20-170
- cholcov 20-175
- circuit boards 20-75
- city block metric 13-10 20-1694 20-1701
- classical multidimensional scaling
 - cmdscale function 20-277
 - overview 10-3
- classification
 - functions 18-48
 - objects 19-9
 - visualization functions 18-16 18-50
- Classification
 - naive bayes 12-36
 - performance curves 12-39
 - tree bagging 13-144
- classification ensemble methods
 - functions 18-58
- classification trees
 - example 13-47
 - functions 18-52
 - objects 19-9
- classifiers 12-2
- classify 20-242
- cluster 20-262
- cluster analysis
 - functions 18-45
 - hierarchical clustering 11-3
 - K-means clustering 11-21
 - overview 11-2
 - visualization functions 18-15 18-45
- cluster trees
 - constructing clusters from 20-262
 - creating 20-1176
 - creating, from data 20-269
 - inconsistency coefficient 20-963
- cmdscale 20-277

- CML. *See* Canonical Maximum Likelihood
 - combnk 20-301
 - common factors 10-46
 - comparisons, multiple 8-6
 - complete linkage 20-1182
 - Computing, parallel 17-1
 - confidence intervals
 - communicating results of hypothesis tests 7-4
 - confounding effects 15-5
 - confounding patterns 15-7
 - confusionmat 20-349
 - container variables 2-3
 - continuous distributions
 - data 5-4
 - statistics 5-7
 - control charts 16-3
 - controlchart 20-352
 - controlrules 20-358
 - Cook's distance 20-2070
 - cophenet 20-363
 - cophenetic correlation coefficients 11-10 20-363
 - cophenetic distance 11-10
 - copulacdf 20-365
 - copulafit 20-367
 - copulaparam 20-373
 - copulapdf 20-375
 - copularnd 20-379
 - copulas 5-109 B-27
 - copulastat 20-377
 - cordexch 20-381
 - corr 20-386
 - corrcov 20-390
 - correlation
 - functions 18-11
 - Cox proportional hazards fit 20-393
 - coxphfit 20-393
 - criterion function 10-23
 - crosstab 20-401
 - crossval 20-404
 - cumulative distribution
 - functions 18-21
 - cumulative distribution function (cdf)
 - empirical 5-64
 - for parametric estimation 5-63
 - graphing an estimate 4-12
 - curse of dimensionality 10-2
 - cut variables 20-233 20-323 20-336 20-439 20-2062
- D**
- D-optimal designs
 - functions 18-66
 - generating candidate set 20-113
 - overview 15-15
 - data
 - categorical 2-13
 - heterogeneous 2-7
 - landmark 10-14
 - statistical 2-21
 - data containers 2-3
 - data organization
 - functions 18-3
 - objects 19-2
 - data sets
 - normalizing 11-4
 - statistical examples A-2
 - dataset arrays
 - creating 2-22
 - functions 18-6 18-8
 - objects 19-2
 - daugment 20-490
 - dcovary 20-495
 - decision trees
 - computing error rate 20-2493
 - computing response values 20-2497
 - creating 20-2486
 - creating subtrees 20-2489
 - displaying 20-2483

- fitting 20-2486
 - pruning 20-2489
 - density estimation
 - ksdensity function 20-1096
 - descriptive statistics
 - functions 18-9
 - design matrix 9-219
 - design of experiments
 - basic factors 15-6
 - confounding effects 15-5
 - D-optimal designs 15-15
 - fractional factorial designs 15-5
 - full factorial designs 15-3
 - functions 18-65
 - generators 15-6
 - levels 15-3
 - Plackett-Burman designs 15-5
 - resolution 15-6 20-780
 - response surface designs 15-9
 - two-level designs 15-4
 - visualization functions 18-16 18-65
 - dffitool 20-519
 - dimension reduction
 - common factor analysis 20-623
 - multivariate statistical methods 10-2
 - PCA from covariance matrix 20-1676
 - PCA from raw data matrix 20-1894
 - PCA residuals 20-1678
 - discrete distributions 5-8
 - discrete uniform distribution B-114
 - discriminant analysis 12-3
 - functions 18-48
 - dispersion
 - functions 18-9
 - dissimilarity matrices
 - creating 11-4
 - distance classification
 - functions 18-51
 - objects 19-9
 - distance matrices
 - creating 11-4
 - distribution
 - objects 18-17 19-3
 - visualization functions 18-12 18-18
 - distribution fitting
 - functions 5-71 18-26
 - tool 5-12
 - distribution statistics
 - functions 5-69 18-25
 - distributions
 - custom B-28
 - functions that support 5-53
 - disttool 20-548
 - dummyvar 20-553
 - Durbin-Watson test 7-13
 - dwtest 20-556
- E**
- ecdf 20-562
 - ecdfhist 20-565
 - effects
 - fixed 9-217
 - random 9-217
 - statistical 9-217
 - efinv 20-590
 - emission matrices
 - estimating 14-9
 - empirical cumulative distribution function 5-64 20-562
 - ensemble methods
 - objects 19-9 to 19-10
 - equal variances
 - Bartlett multiple-sample test for 7-15
 - F*-test for 7-15
 - erf B-96
 - error function B-96
 - Euclidean distance 13-9 20-1694 20-1700
 - evcdf 20-586
 - evfit 20-588

evlike 20-601
 evpdf 20-602
 evrnd 20-603
 evstat 20-604
 expcdf 20-605
 expectation maximization (EM) algorithm
 cluster analysis 11-2
 Gaussian mixture models 5-100 11-28
 expfit 20-607
 expinv 20-614
 explike 20-616
 exponential distribution B-29
 exppdf 20-620
 exprnd 20-621
 expstat 20-622
 extrapolated 20-1951
 extreme value distribution B-32
 extreme value fit 20-588

F

F distribution B-38
F-test, one-sample 7-15
 factor analysis
 functions 18-44
 maximum likelihood 20-623
 factoran 20-623
 factorial designs
 fractional 15-5
 full 15-3
 generating full 20-792
 fcdf 20-638
 feature selection
 functions 18-43
 overview 10-23
 sequential 10-23
 feature transformation
 functions 18-43
 overview 10-28
 ff2n 20-649

file I/O
 functions 18-2
 filter methods
 feature selection 20-2234
 finv 20-653
 fitdist 20-750
 folds
 partition 20-452
 fpdf 20-775
 fracfactgen 20-780
 fractional factorial designs
 functions 18-66
 overview 15-5
 friedman 20-783
 Friedman's test 8-37
 Friedman's test 7-13
 frnd 20-787
 fstat 20-788
 fsurfht 20-789
 full factorial designs
 functions 18-65
 generating 20-792
 overview 15-3
 fullfact 20-792
 functions
 vectorized 2-9
 furthest neighbor linkage 20-1182

G

gagerr 20-793
 gamcdf 20-798
 gamfit 20-800
 gaminv 20-802
 gamlike 20-804
 gamma distribution B-40
 gampdf 20-806
 gamrnd 20-808
 gamstat 20-809
 Gaussian distribution B-43

- Gaussian mixture distributions B-44
- Gaussian mixture models
 - functions 18-46
 - objects 19-5
- generalized extreme value distribution B-45
- generalized linear regression
 - functions 18-39
- generalized Pareto distribution B-50
- geocdf 20-830
- geoinv 20-831
- geomean 20-832
- geometric distribution B-54
- geopdf 20-833
- geornd 20-834
- geostat 20-835
- gevcdf 20-840
- gevfit 20-841
- gevinv 20-843
- gevlike 20-844
- gevpdf 20-845
- gevrnd 20-846
- gevstat 20-848
- gline 20-849
- glmfit 20-851
- glmval 20-856
- glyphplot 20-859
- gname 20-871
- gpcdf 20-873
- gpfit 20-874
- gpinv 20-876
- gplike 20-877
- gplotmatrix 20-879
- gppdf 20-878
- gprnd 20-882
- gpstat 20-883
- graphical user interfaces
 - functions 18-70
- group mean clusters, plot 8-44
- grouped plot matrices 8-40
- grp2idx 20-886

gscatter 20-909

H

- harmmean 20-917
- heterogeneous data
 - storing, in MATLAB 2-7
- hidden Markov models
 - functions 18-64
 - overview 14-5
- hierarchical clustering
 - cluster analysis 11-3
 - computing inconsistency coefficient 20-963
 - constructing clusters 20-262
 - cophenetic correlation coefficients 20-363
 - creating cluster trees 20-1176
 - creating clusters 11-16
 - creating clusters from data 20-269
 - determining proximity 20-1692 20-1698
 - evaluating cluster formation 20-363
 - functions 18-45
 - grouping objects 11-6
 - inconsistency coefficient 20-963
 - procedure 11-3
- hist3 20-918
- HMM 14-5
- HMM functions 14-7
- hmmdecode 20-935
- hmmestimate 14-9 20-937
- hmmgenerate 20-940
- hmmtrain 14-10 20-942
- hmmviterbi 20-945
- holdout
 - partition 20-452
- Hotelling's T-squared 10-42
- hougen 20-949
- hygecdf 20-950
- hygeinv 20-951
- hygepdf 20-952
- hygernd 20-953

hygestat 20-954
hypergeometric distribution B-56
hypotheses B-39
hypothesis tests
 assumptions 7-5
 functions 18-33
 functions that support 7-13
 power 7-4 20-2219

I

icdf 20-955
IFM. *See* Inference Functions for Margins method
incomplete beta function B-4
incomplete gamma function B-40
inconsistency coefficient 20-963
inconsistent 20-963
Inference Functions for Margins (IFM)
 method 20-368
initial state distribution
 changing 14-12
interaction effects
 designed experiments 15-2
 two-way ANOVA 8-9
interactionplot 20-971
interquartile range (iqr) 3-6
inverse cumulative distribution
 functions 5-67 18-23
inverse Gaussian distribution B-58
inverse Wishart distribution B-59
invpred 20-978
iqr 20-981
iwishrnd 20-1006

J

jackknife 20-1007
Jarque-Bera test 7-13 20-1009
jbttest 20-1009
Johnson system of distributions 6-25 B-61

johnsrnd 20-1012

K

K-means clustering
 cluster separation 11-22
 functions 18-46
 local minima 11-26
 number of clusters 11-23
 overview 11-21
 silhouette plot 20-2282
Kaplan-Meier cumulative distribution
 function 20-562
kernel bandwidth 5-58
kernel smoothing functions
 specifying 5-60
kmeans 20-1067
Kolmogorov-Smirnov test
 one-sample 7-13
 two-sample 7-14
Kruskal-Wallis test 7-13 8-36
kruskalwallis 20-1092
ksdensity 20-1096
kstest 20-1102
kstest2 20-1107
kurtosis 20-1111

L

landmark data 10-14
latin hypercube designs
 functions 18-66
latin hypercube sample 20-1151
 normal distribution 20-1152
least squares
 iteratively reweighted 9-113
leverage 20-1149
lhsdesign 20-1151
lhsnorm 20-1152
likelihood function 20-64

- Lilliefors test 7-14
 - example 7-7
- lillietest 20-1153
- linear hypothesis test 7-14
- linear regression
 - functions 18-37
 - ridge 9-116
- linear transformations
 - Procrustes 20-1924
- linhpytest 20-1174
- link functions 9-142
- linkage
 - average 20-1182
 - centroid 20-1182
 - complete 20-1182
 - furthest neighbor 20-1182
 - nearest neighbor 20-1182
 - single 20-1182
 - ward 20-1183
 - weighted average distance 20-1183
- loadings 10-46
- logistic distribution B-62
- logistic models 9-155
- loglogistic distribution B-63
- logncdf 20-1187
- lognfit 20-1189
- logninv 20-1191
- lognlike 20-1193
- lognormal distribution B-64
- lognormal fit 20-1189
- lognpdf 20-1194
- lognrnd 20-1196
- lognstat 20-1198
- loss
 - prediction 20-2231
- lsline 20-1238

- M**
- mad 20-1240
- mahal 20-1242
- Mahalanobis distance
 - computing 20-1242 20-1246
 - in cluster analysis 13-10 20-1694 20-1701
- main effects 15-2
- maineffectsplo 20-1250
- Mann-Whitney U-test 20-2011
- MANOVA 8-39
- manova1 20-1256
- manovacluster 20-1260
- Markov chains
 - emission matrix 14-4
 - emissions 14-4
 - initial state 14-4
 - Monte Carlo simulations 6-13
 - overview 14-3
 - transition matrices 14-4
- Markov models
 - hidden
 - functions for 14-7
 - generating test sequences for 14-8
 - overview 14-5
 - state diagram 14-3
- maximum likelihood
 - estimation 5-71
 - factor analysis 20-623
- MCMC 6-13
- MDS. *See* multidimensional scaling
- mdscale 20-1284
- mean
 - of probability distribution 5-69
- mean absolute deviation 20-1240
- mean squares (MS) 20-24
- measures of
 - central tendency 3-3
 - dispersion 3-5
- median absolute deviation 20-1240
- metric multidimensional scaling 10-3
 - See also* classical multidimensional scaling
- mhsample 20-1311

- Minkowski metric 13-10 20-1695 20-1701
 - missing data 3-21
 - missing values
 - functions 18-10
 - mixed-effects models 9-218
 - mle 20-1316
 - MLE. *See* maximum likelihood — estimation
 - mlecov 20-1324
 - mnpdf 20-1328
 - mnrfit 20-1330
 - mnrnd 20-1337
 - mnrval 20-1339
 - model assessment
 - functions 18-47
 - objects 19-6
 - models
 - mixed-effects 9-218
 - moment 20-1345
 - MS. *See* mean squares
 - multcompare 20-1348
 - multicollinearity 20-2180
 - addressed by ridge regression 9-116
 - multidimensional arrays
 - classical (metric) scaling 20-277
 - multidimensional scaling (MDS)
 - classical (metric) 10-3
 - functions 18-42
 - multinomial distribution B-67
 - multiple comparison procedure 20-1348
 - multivariate analysis of variance
 - example 8-39
 - multivariate distributions 5-9
 - multivariate Gaussian distribution B-70
 - multivariate normal distribution B-71
 - multivariate regression 9-140
 - multivariate statistics
 - analysis of variance 8-39
 - functions 18-42
 - principal component analysis 10-31
 - visualization functions 18-15 18-42
 - multivariate t distribution B-77
 - multivarichart 20-1358
 - mvncdf 20-1362
 - mvnpdf 20-1366
 - mvnrnd 20-1386
 - mvregresslike 20-1384
 - mvtcdf 20-1388
 - mvtpdf 20-1392
 - mvtrnd 20-1394
- ## N
- Nakagami distribution B-83
 - nancov 20-1401
 - nanmax 20-1403
 - nanmean 20-1404
 - nanmedian 20-1405
 - nanmin 20-1406
 - NaNs
 - coding missing values as 3-21
 - nanstd 20-1407
 - nansum 20-1408
 - nanvar 20-1409
 - nbincdf 20-1411
 - nbinfit 20-1413
 - nbininv 20-1414
 - nbinpdf 20-1415
 - nbinrnd 20-1417
 - nbinstat 20-1418
 - ncfcdf 20-1420
 - ncfinv 20-1422
 - ncfpdf 20-1424
 - ncfrnd 20-1426
 - ncfstat 20-1428
 - nctcdf 20-1432
 - nctinv 20-1434
 - nctpdf 20-1435
 - nctrnd 20-1437
 - nctstat 20-1438
 - ncx2cdf 20-1440

- ncx2inv 20-1442
 - ncx2pdf 20-1443
 - ncx2rnd 20-1445
 - ncx2stat 20-1446
 - nearest neighbor linkage 20-1182
 - negative binomial distribution
 - confidence intervals 20-1413
 - cumulative distribution function (cdf) 20-1411
 - definition B-85
 - inverse cumulative distribution function (cdf) 20-1414
 - mean and variance 20-1418
 - modeling number of auto accidents B-86
 - nbincdf function 20-1411
 - nbiniinv function 20-1414
 - nbincpdf function 20-1415
 - parameter estimates 20-1413
 - probability density function (pdf) 20-1415
 - random matrices 20-1417
 - negative binomial fit 20-1413
 - negative log-likelihood
 - functions 5-78 18-28
 - Newton's method 20-802
 - nlintool 20-1475
 - nlmefit 20-1477
 - nlparci 20-1511
 - nnmf 20-1526
 - noncentral F distribution B-91
 - nonlinear mixed effects 20-1477
 - nonlinear regression
 - functions 18-40
 - nonnegative matrix factorization
 - dimension-reduction technique 10-29
 - functions 18-43
 - nonparametric distributions 5-9 B-95
 - normal distribution B-96
 - normal fit 20-1569
 - normal probability plots 4-8
 - normalizing
 - data sets 11-4
 - normcdf 20-1567
 - normfit 20-1569
 - norminv 20-1571
 - normlike 20-1573
 - normpdf 20-1574
 - normplot 20-1576
 - normrnd 20-1578
 - normspec 20-1579
 - normstat 20-1581
 - null hypotheses 7-3
 - numerical arrays 2-4
- O**
- one-sample Kolmogorov-Smirnov test 7-13
 - online updates 20-1072
 - outliers
 - measures resistant to 3-3
- P**
- p values 7-3
 - parallel regression 20-1331
 - Parallel statistics 17-1
 - parallelcoords 20-1638
 - Pareto distribution B-99
 - partial least-squares regression 9-134
 - partialcorr 20-1656
 - PCA. *See* principal component analysis
 - pcacov 20-1676
 - pcares 20-1678
 - pdf 20-1681
 - pdist 20-1692
 - Pearson system of distributions 6-25 B-100
 - pearsrnd 20-1704
 - perms 20-1718
 - piecewise distribution fitting
 - functions 18-27
 - piecewise distributions B-101

- functions 18-31
- objects 19-4
- Plackett-Burman designs 15-5
- plsregress 20-1794
- poisscdf 20-1802
- poissfit 20-1804
- poissinv 20-1805
- Poisson distribution B-102
- Poisson fit 20-1804
- poisspdf 20-1806
- poissrnd 20-1807
- poisstat 20-1808
- polyconf 20-1809
- polytool 20-1815
- posterior state probabilities
 - estimating 14-11
- power
 - hypothesis tests 7-4
- principal component analysis (PCA)
 - component scores 10-37
 - component variances 10-40
 - functions 18-43
 - Hotelling's T-squared 10-42
 - overview 10-31
 - principal components 10-35
 - quality of life example 10-33
 - scree plots 10-41
- principal coordinates analysis 10-4
- princomp 20-1894
- probabilities
 - posterior state, estimating 14-11
- probability density
 - functions 5-53 18-19
- probability density estimation
 - comparing estimates 5-61
 - function 20-1096
 - kernel bandwidth 5-58
 - kernel smoothing functions 5-60
 - nonparametric estimation 5-56

- Probability Distribution Function Tool 5-10
- probability distributions
 - disttool 5-10
 - functions 18-17
 - functions that support 5-3
 - mean and variance 5-69
 - objects 19-3
 - piecewise 5-71
- probability mass functions
 - pmf 5-53
- probplot 20-1919
- procrustes 20-1924
- Procrustes analysis 10-14 20-1924
 - functions 18-42
- pseudorandom numbers
 - generating 6-2

Q

- qqplot 20-1951
- QR* decomposition 20-2070
- QRNG (quasi-random number generator) 6-15
- quality assurance 20-75
- quantile-quantile plots 4-10
- quasi-random designs
 - functions 18-67
 - objects 19-11
- quasi-random numbers
 - functions 18-30
 - generating 6-15
 - objects 19-3
 - sequences
 - leaping 6-17
 - point set 6-17
 - scrambling 6-17
 - skipping 6-17
 - streams 6-23
 - state 6-23

R

- randg 20-1964
- random 20-1967
- random number generation
 - acceptance-rejection methods 6-9
 - direct methods 6-5
 - inversion methods 6-7
 - methods 6-5
- Random Number Generation Tool 5-50
- random number generators (RNGs) 5-81 6-2
- random numbers
 - functions 18-28
- random samples
 - inverse Wishart 20-1006
 - latin hypercube 20-1151
 - latin hypercube with normal distribution 20-1152
 - Wishart 20-2589
- randsample 20-1988
- randtool 20-1990
- range 20-1993
- raylcdf 20-2020
- Rayleigh distribution B-104
- Rayleigh fit 20-2021
- raylfit 20-2021
- raylinv 20-2022
- raylpdf 20-2023
- raylrnd 20-2024
- raylstat 20-2025
- rcoplot 20-2026
- refcurve 20-2028
- refline 20-2032
- regress 20-2034
- regression
 - adjusted R -square statistic 20-2070
 - change in covariance 20-2070
 - change in fitted values 20-2070
 - coefficient covariance 20-2070
 - coefficients 20-2070
 - delete-1 coefficients 20-2070
 - delete-1 variance 20-2070
 - F distribution B-39
 - F statistic 20-2070
 - fitted values 20-2070
 - hat matrix 20-2070
 - leverage 20-2070
 - mean squared error 20-2070
 - multivariate 9-140
 - partial least squares 9-134
 - projection matrix 20-2070
 - R -square statistic 20-2070
 - residuals 20-2070
 - scaled change in coefficients 20-2070
 - scaled change in fitted values 20-2070
 - t statistic 20-2070
- regression analysis
 - functions 18-36
 - visualization functions 18-14 18-36
- regression ensemble methods
 - functions 18-60
- regression trees
 - example 13-50
 - functions 18-55
 - objects 19-10
- regstats 20-2070
- relative efficiency 20-981
- resampling
 - functions 18-10
 - statistics 3-16
- residuals
 - standardized 20-2070
 - studentized 20-2070
- response surface
 - designs
 - functions 18-66
- response surfaces
 - designs
 - Box-Behnken 15-13
 - central composite 15-9
 - overview 15-9

- resubstitution error 20-1533
- Rician distribution B-106
- ridge 20-2179
- ridge parameters 9-116 20-2180
- ridge regression 9-116 20-2179
- ridge trace 20-2179
- RNGs. *See* random number generators
- robust linear fit 20-1951
- robust linear regression 20-2191
- robustdemo 20-2187
- robustfit 20-2191
- rotatable designs 15-11
- rotatefactors 20-2198
- rowexch 20-2202
- rsmdemo 20-2207
- rstool 20-2212
- runs test 7-14
- runstest 20-2216

- S**
- sampsizepwr 20-2219
- SBS. *See* sequential backward selection
- scaling arrays
 - classical multidimensional 20-277
- scatter
 - visualization functions 18-13
- scatter plots
 - functions that produce 4-3
 - grouped 8-40
- scatterhist 20-2222
- scree plots 10-41
- sequential backward selection (SBS) 10-24
- sequential feature selection
 - criterion 10-23
- sequential forward selection (SFS) 10-24
- sequentialfs 20-2231
- SFS. *See* sequential forward selection
- shape
 - functions 18-10
- Shepard plots 10-11
- sign tests 7-14
- significance levels 7-3
- silhouette 20-2282
- similarity matrices
 - creating 11-4
- single linkage 20-1182
- skewness 20-2297
- SPC. *See* statistical process control
- specific variance 10-46
- squareform 20-2311
- SS. *See* sum of squares
- standard normal 20-1574
- standardized Euclidean distance 13-9 20-1694
 - 20-1700
- state sequences
 - estimating 14-8
- statistical arrays 2-11
- statistical data 2-21
- statistical functions
 - operating on numerical data 2-9
 - vectorized 2-9
- statistical process control
 - capability studies 16-6
 - control charts 16-3
 - functions 18-69
 - visualization functions 18-16 18-69
- statistical visualization
 - functions 18-12
- stepwise 20-2344
- stepwisefit 20-2384
- structure arrays
 - storing heterogeneous data in 2-7
- Student's *t* distribution B-108
 - noncentral B-93
- sum of squares (SS) 20-24
- summaries
 - functions 18-9
- supported distribution fitting
 - functions 18-26

surfht 20-2419

T

t location-scale distribution B-110

t-tests

- one-sample 7-14
- paired-sample 7-14
- two-sample 7-15

tab-delimited data

reading from file 20-2433

tabular data

reading from file 20-2427

tabulate 20-2426

tblread 20-2427

tblwrite 20-2429

tcdf 20-2431

tdfread 20-2433

test data 12-2

test sequences

generating, for hidden Markov model 14-8

test statistics 7-3

tiedrank 20-2461

tinvs 20-2463

tpdf 20-2464

training data 12-2

transition matrices

estimating 14-9

treatments

experimental 15-3

treedisp 20-2483

treefit 20-2486

treeprune 20-2489

trees 20-2486

See also decision trees

treetest 20-2493

treeval 20-2497

trimmean 20-2499

trnd 20-2503

tstat 20-2504

ttest 20-2505

ttest2 20-2509

two-level designs 15-4

two-sample Kolmogorov-Smirnov test 7-14

two-way ANOVA 8-9

type I errors 7-3

type II errors 7-4

U

unidcdf 20-2528

unidinv 20-2529

unidpdf 20-2530

unidrnd 20-2531

unidstat 20-2532

unifcdf 20-2533

unifinv 20-2534

unifit 20-2535

uniform distribution B-112

uniformly distributed fit 20-2535

unifpdf 20-2536

unifrnd 20-2537

unifstat 20-2539

utility functions 18-71

V

variables

container 2-3

variances

of probability distribution 5-69

vartest 20-2555

vartest2 20-2557

vartestn 20-2559

vectorization

advantages of 2-9

W

Wald distribution B-58

ward linkage 20-1183

wblcdf 20-2573
wblfit 20-2575
wblinv 20-2577
wbllike 20-2580
wblpdf 20-2582
wblplot 20-2584
wblrnd 20-2587
wblstat 20-2588
Weibull distribution B-116
Weibull fit 20-2575
Weibull, Waloddi B-116
weighted average distance linkage 20-1183
whiskers
 on plots 4-7
Wilcoxon rank sum test 7-14
Wilcoxon signed rank tests 7-14

Wishart distribution B-119
Wishart random matrix 20-2589
 inverse 20-1006
wishrnd 20-2589
wrapper methods
 feature selection 20-2234

X

x2fx 20-2592
xptread 20-2591

Z

z-test, one-sample 7-15
ztest 20-2607