MATLAB®

The Language of Technical Computing

Computation

Visualization

Programming

MATLAB Function Reference
Volume 1: A - E

Version 6

The MathWorks

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Contents

1 Functions – By Category

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Functions – By Category

The MATLAB Function Reference contains descriptions of all MATLAB commands and functions.

Select a category from the following table to see a list of related functions.

Development Environment	Startup, Command Window, help, editing and debugging, other general functions
Mathematics	Arrays and matrices, linear algebra, data analysis, other areas of mathematics
Programming and Data Types	Function/expression evaluation, program control, function handles, object oriented programming, error handling, operators, data types, dates and times, timers
File I/O	General and low-level file I/O, plus specific file formats, like audio, spreadsheet, HDF, images
Graphics	Line plots, annotating graphs, specialized plots, images, printing, Handle Graphics
3-D Visualization	Surface and mesh plots, view control, lighting and transparency, volume visualization.
Creating Graphical User Interface	GUIDE, programming graphical user interfaces.
External Interfaces	Java, COM, Serial Port functions.

See Simulink, Stateflow, Real-Time Workshop, and the individual toolboxes for lists of their functions

Development Environment

General functions for working in MATLAB, including functions for startup, Command Window, help, and editing and debugging.

"Starting and Quitting"	Startup and shutdown options
"Command Window"	Controlling Command Window
"Getting Help"	Finding information
"Workspace, File, and Search Path"	File, search path, variable management
"Programming Tools"	Editing and debugging, source control, Notebook
"System"	Identifying current computer, license, product version, and more
"Performance Improvement Tools and Techniques"	Improving and assessing performance, e.g., profiling and memory use

Starting and Quitting

`exit`	Terminate MATLAB (same as `quit`)
`finish`	MATLAB termination M-file
`matlab`	Start MATLAB (UNIX systems only)
`matlabrc`	MATLAB startup M-file for single user systems or administrators
`quit`	Terminate MATLAB
`startup`	MATLAB startup M-file for user-defined options

Command Window

`clc`	Clear Command Window
`diary`	Save session to file
`dos`	Execute DOS command and return result
`format`	Control display format for output
`home`	Move cursor to upper left corner of Command Window
`more`	Control paged output for Command Window
`notebook`	Open M-book in Microsoft Word (Windows only)
`system`	Execute operating system command and return result
`unix`	Execute UNIX command and return result

Getting Help

`doc`	Display online documentation in MATLAB Help browser
`demo`	Access product demos via Help browser
`docopt`	Location of help file directory for UNIX platforms
`help`	Display help for MATLAB functions in Command Window
`helpbrowser`	Display Help browser for access to extensive online help
`helpwin`	Display M-file help, with access to M-file help for all functions
`info`	Display information about The MathWorks or products
`lookfor`	Search for specified keyword in all help entries
`support`	Open MathWorks Technical Support Web page
`web`	Point Help browser or Web browser to file or Web site
`whatsnew`	Display information about MATLAB and toolbox releases

Workspace, File, and Search Path

- "Workspace"
- "File"
- "Search Path"

Workspace

`assignin`	Assign value to workspace variable
`clear`	Remove items from workspace, freeing up system memory
`evalin`	Execute string containing MATLAB expression in a workspace
`exist`	Check if variable or file exists
`openvar`	Open workspace variable in Array Editor for graphical editing
`pack`	Consolidate workspace memory
`which`	Locate functions and files
`who`, `whos`	List variables in the workspace
`workspace`	Display Workspace browser, a tool for managing the workspace

File

`cd`	Change working directory
`copyfile`	Copy file or directory
`delete`	Delete files or graphics objects
`dir`	Display directory listing
`exist`	Check if a variable or file exists
`fileattrib`	Set or get attributes of file or directory
`filebrowser`	Display Current Directory browser, a tool for viewing files
`lookfor`	Search for specified keyword in all help entries
`ls`	List directory on UNIX

`matlabroot`	Return root directory of MATLAB installation
`mkdir`	Make new directory
`movefile`	Move file or directory
`pwd`	Display current directory
`rehash`	Refresh function and file system caches
`rmdir`	Remove directory
`type`	List file
`what`	List MATLAB specific files in current directory
`which`	Locate functions and files

See also “File I/O” functions.

Search Path

`addpath`	Add directories to MATLAB search path
`genpath`	Generate path string
`partialpath`	Partial pathname
`path`	View or change the MATLAB directory search path
`path2rc`	Save current MATLAB search path to `pathdef.m` file
`pathtool`	Open **Set Path** dialog box to view and change MATLAB path
`rmpath`	Remove directories from MATLAB search path

Programming Tools

- “Editing and Debugging”
- “Source Control”
- “Notebook”

Editing and Debugging

`dbclear`	Clear breakpoints
`dbcont`	Resume execution
`dbdown`	Change local workspace context
`dbquit`	Quit debug mode
`dbstack`	Display function call stack
`dbstatus`	List all breakpoints
`dbstep`	Execute one or more lines from current breakpoint
`dbstop`	Set breakpoints in M-file function
`dbtype`	List M-file with line numbers
`dbup`	Change local workspace context
`edit`	Edit or create M-file
`keyboard`	Invoke the keyboard in an M-file

Source Control

`checkin`	Check file into source control system
`checkout`	Check file out of source control system
`cmopts`	Get name of source control system
`customverctrl`	Allow custom source control system
`undocheckout`	Undo previous checkout from source control system
`verctrl`	Version control operations on PC platforms

Notebook

`notebook`	Open M-book in Microsoft Word (Windows only)

System

`computer`	Identify information about computer on which MATLAB is running
`javachk`	Generate error message based on Java feature support
`license`	Show license number for MATLAB
`prefdir`	Return directory containing preferences, history, and `.ini` files
`usejava`	Determine if a Java feature is supported in MATLAB
`ver`	Display version information for MathWorks products
`version`	Get MATLAB version number

Performance Improvement Tools and Techniques

`memory`	Help for memory limitations
`pack`	Consolidate workspace memory
`profile`	Optimize performance of M-file code
`profreport`	Generate profile report
`rehash`	Refresh function and file system caches
`sparse`	Create sparse matrix
`zeros`	Create array of all zeros

Mathematics

Functions for working with arrays and matrices, linear algebra, data analysis, and other areas of mathematics.

"Arrays and Matrices"	Basic array operators and operations, creation of elementary and specialized arrays and matrices
"Linear Algebra"	Matrix analysis, linear equations, eigenvalues, singular values, logarithms, exponentials, factorization
"Elementary Math"	Trigonometry, exponentials and logarithms, complex values, rounding, remainders, discrete math
"Data Analysis and Fourier Transforms"	Descriptive statistics, finite differences, correlation, filtering and convolution, fourier transforms
"Polynomials"	Multiplication, division, evaluation, roots, derivatives, integration, eigenvalue problem, curve fitting, partial fraction expansion
"Interpolation and Computational Geometry"	Interpolation, Delaunay triangulation and tessellation, convex hulls, Voronoi diagrams, domain generation
"Coordinate System Conversion"	Conversions between Cartesian and polar or spherical coordinates
"Nonlinear Numerical Methods"	Differential equations, optimization, integration
"Specialized Math"	Airy, Bessel, Jacobi, Legendre, beta, elliptic, error, exponential integral, gamma functions
"Sparse Matrices"	Elementary sparse matrices, operations, reordering algorithms, linear algebra, iterative methods, tree operations
"Math Constants"	Pi, imaginary unit, infinity, Not-a-Number, largest and smallest positive floating point numbers, floating point relative accuracy

Arrays and Matrices

- "Basic Information"
- "Operators"
- "Operations and Manipulation"
- "Elementary Matrices and Arrays"
- "Specialized Matrices"

Basic Information

`disp`	Display array
`display`	Display array
`isempty`	True for empty matrix
`isequal`	True if arrays are identical
`islogical`	True for logical array
`isnumeric`	True for numeric arrays
`issparse`	True for sparse matrix
`length`	Length of vector
`ndims`	Number of dimensions
`numel`	Number of elements
`size`	Size of matrix

Operators

`+`	Addition
`+`	Unary plus
`-`	Subtraction
`-`	Unary minus
`*`	Matrix multiplication
`^`	Matrix power
`\`	Backslash or left matrix divide
`/`	Slash or right matrix divide
`'`	Transpose
`.'`	Nonconjugated transpose
`.*`	Array multiplication (element-wise)
`.^`	Array power (element-wise)
`.\`	Left array divide (element-wise)
`./`	Right array divide (element-wise)

Operations and Manipulation

`:` (colon)	Index into array, rearrange array
`blkdiag`	Block diagonal concatenation

`cat`	Concatenate arrays
`cross`	Vector cross product
`cumprod`	Cumulative product
`cumsum`	Cumulative sum
`diag`	Diagonal matrices and diagonals of matrix
`dot`	Vector dot product
`end`	Last index
`find`	Find indices of nonzero elements
`fliplr`	Flip matrices left-right
`flipud`	Flip matrices up-down
`flipdim`	Flip matrix along specified dimension
`horzcat`	Horizontal concatenation
`ind2sub`	Multiple subscripts from linear index
`ipermute`	Inverse permute dimensions of multidimensional array
`kron`	Kronecker tensor product
`max`	Maximum elements of array
`min`	Minimum elements of array
`permute`	Rearrange dimensions of multidimensional array
`prod`	Product of array elements
`repmat`	Replicate and tile array
`reshape`	Reshape array
`rot90`	Rotate matrix 90 degrees
`sort`	Sort elements in ascending order
`sortrows`	Sort rows in ascending order
`sum`	Sum of array elements
`sqrtm`	Matrix square root
`sub2ind`	Linear index from multiple subscripts
`tril`	Lower triangular part of matrix
`triu`	Upper triangular part of matrix
`vertcat`	Vertical concatenation

See also "Linear Algebra" for other matrix operations.
See also "Elementary Math" for other array operations.

Elementary Matrices and Arrays

`:` (colon)	Regularly spaced vector
`blkdiag`	Construct block diagonal matrix from input arguments
`diag`	Diagonal matrices and diagonals of matrix
`eye`	Identity matrix
`freqspace`	Frequency spacing for frequency response
`linspace`	Generate linearly spaced vectors
`logspace`	Generate logarithmically spaced vectors

`meshgrid`	Generate X and Y matrices for three-dimensional plots
`ndgrid`	Arrays for multidimensional functions and interpolation
`ones`	Create array of all ones
`rand`	Uniformly distributed random numbers and arrays
`randn`	Normally distributed random numbers and arrays
`repmat`	Replicate and tile array
`zeros`	Create array of all zeros

Specialized Matrices

`compan`	Companion matrix
`gallery`	Test matrices
`hadamard`	Hadamard matrix
`hankel`	Hankel matrix
`hilb`	Hilbert matrix
`invhilb`	Inverse of Hilbert matrix
`magic`	Magic square
`pascal`	Pascal matrix
`rosser`	Classic symmetric eigenvalue test problem
`toeplitz`	Toeplitz matrix
`vander`	Vandermonde matrix
`wilkinson`	Wilkinson's eigenvalue test matrix

Linear Algebra

- "Matrix Analysis"
- "Linear Equations"
- "Eigenvalues and Singular Values"
- "Matrix Logarithms and Exponentials"
- "Factorization"

Matrix Analysis

`cond`	Condition number with respect to inversion
`condeig`	Condition number with respect to eigenvalues
`det`	Determinant
`norm`	Matrix or vector norm
`normest`	Estimate matrix 2-norm
`null`	Null space
`orth`	Orthogonalization
`rank`	Matrix rank
`rcond`	Matrix reciprocal condition number estimate

`rref`	Reduced row echelon form
`subspace`	Angle between two subspaces
`trace`	Sum of diagonal elements

Linear Equations

\ and /	Linear equation solution
`chol`	Cholesky factorization
`cholinc`	Incomplete Cholesky factorization
`cond`	Condition number with respect to inversion
`condest`	1-norm condition number estimate
`funm`	Evaluate general matrix function
`inv`	Matrix inverse
`lscov`	Least squares solution in presence of known covariance
`lsqnonneg`	Nonnegative least squares
`lu`	LU matrix factorization
`luinc`	Incomplete LU factorization
`pinv`	Moore-Penrose pseudoinverse of matrix
`qr`	Orthogonal-triangular decomposition
`rcond`	Matrix reciprocal condition number estimate

Eigenvalues and Singular Values

`balance`	Improve accuracy of computed eigenvalues
`cdf2rdf`	Convert complex diagonal form to real block diagonal form
`condeig`	Condition number with respect to eigenvalues
`eig`	Eigenvalues and eigenvectors
`eigs`	Eigenvalues and eigenvectors of sparse matrix
`gsvd`	Generalized singular value decomposition
`hess`	Hessenberg form of matrix
`poly`	Polynomial with specified roots
`polyeig`	Polynomial eigenvalue problem
`qz`	QZ factorization for generalized eigenvalues
`rsf2csf`	Convert real Schur form to complex Schur form
`schur`	Schur decomposition
`svd`	Singular value decomposition
`svds`	Singular values and vectors of sparse matrix

Matrix Logarithms and Exponentials

`expm`	Matrix exponential
`logm`	Matrix logarithm
`sqrtm`	Matrix square root

Factorization

`balance`	Diagonal scaling to improve eigenvalue accuracy
`cdf2rdf`	Complex diagonal form to real block diagonal form
`chol`	Cholesky factorization
`cholinc`	Incomplete Cholesky factorization
`cholupdate`	Rank 1 update to Cholesky factorization
`lu`	LU matrix factorization
`luinc`	Incomplete LU factorization
`planerot`	Givens plane rotation
`qr`	Orthogonal-triangular decomposition
`qrdelete`	Delete column or row from QR factorization
`qrinsert`	Insert column or row into QR factorization
`qrupdate`	Rank 1 update to QR factorization
`qz`	QZ factorization for generalized eigenvalues
`rsf2csf`	Real block diagonal form to complex diagonal form

Elementary Math

- “Trigonometric”
- “Exponential”
- “Complex”
- “Rounding and Remainder”
- “Discrete Math (e.g., Prime Factors)”

Trigonometric

`acos`	Inverse cosine
`acosh`	Inverse hyperbolic cosine
`acot`	Inverse cotangent
`acoth`	Inverse hyperbolic cotangent
`acsc`	Inverse cosecant
`acsch`	Inverse hyperbolic cosecant
`asec`	Inverse secant
`asech`	Inverse hyperbolic secant
`asin`	Inverse sine
`asinh`	Inverse hyperbolic sine
`atan`	Inverse tangent
`atanh`	Inverse hyperbolic tangent
`atan2`	Four-quadrant inverse tangent
`cos`	Cosine
`cosh`	Hyperbolic cosine
`cot`	Cotangent
`coth`	Hyperbolic cotangent

`csc`	Cosecant
`csch`	Hyperbolic cosecant
`sec`	Secant
`sech`	Hyperbolic secant
`sin`	Sine
`sinh`	Hyperbolic sine
`tan`	Tangent
`tanh`	Hyperbolic tangent

Exponential

`exp`	Exponential
`log`	Natural logarithm
`log2`	Base 2 logarithm and dissect floating-point numbers into exponent and mantissa
`log10`	Common (base 10) logarithm
`nextpow2`	Next higher power of 2
`pow2`	Base 2 power and scale floating-point number
`reallog`	Natural logarithm for nonnegative real arrays
`realpow`	Array power for real-only output
`realsqrt`	Square root for nonnegative real arrays
`sqrt`	Square root

Complex

`abs`	Absolute value
`angle`	Phase angle
`complex`	Construct complex data from real and imaginary parts
`conj`	Complex conjugate
`cplxpair`	Sort numbers into complex conjugate pairs
`i`	Imaginary unit
`imag`	Complex imaginary part
`isreal`	True for real array
`j`	Imaginary unit
`real`	Complex real part
`unwrap`	Unwrap phase angle

Rounding and Remainder

`fix`	Round towards zero
`floor`	Round towards minus infinity
`ceil`	Round towards plus infinity
`round`	Round towards nearest integer
`mod`	Modulus after division
`rem`	Remainder after division
`sign`	Signum

Discrete Math (e.g., Prime Factors)

`factor`	Prime factors
`factorial`	Factorial function
`gcd`	Greatest common divisor
`isprime`	True for prime numbers
`lcm`	Least common multiple
`nchoosek`	All combinations of N elements taken K at a time
`perms`	All possible permutations
`primes`	Generate list of prime numbers
`rat`, `rats`	Rational fraction approximation

Data Analysis and Fourier Transforms

- “Basic Operations”
- “Finite Differences”
- “Correlation”
- “Filtering and Convolution”
- “Fourier Transforms”

Basic Operations

`cumprod`	Cumulative product
`cumsum`	Cumulative sum
`cumtrapz`	Cumulative trapezoidal numerical integration
`max`	Maximum elements of array
`mean`	Average or mean value of arrays
`median`	Median value of arrays
`min`	Minimum elements of array
`prod`	Product of array elements
`sort`	Sort elements in ascending order
`sortrows`	Sort rows in ascending order
`std`	Standard deviation
`sum`	Sum of array elements
`trapz`	Trapezoidal numerical integration
`var`	Variance

Finite Differences

`del2`	Discrete Laplacian
`diff`	Differences and approximate derivatives
`gradient`	Numerical gradient

Correlation

`corrcoef`	Correlation coefficients
`cov`	Covariance matrix
`subspace`	Angle between two subspaces

Filtering and Convolution

`conv`	Convolution and polynomial multiplication
`conv2`	Two-dimensional convolution
`convn`	N-dimensional convolution
`deconv`	Deconvolution and polynomial division
`detrend`	Linear trend removal
`filter`	Filter data with infinite impulse response (IIR) or finite impulse response (FIR) filter
`filter2`	Two-dimensional digital filtering

Fourier Transforms

`abs`	Absolute value and complex magnitude
`angle`	Phase angle
`fft`	One-dimensional discrete Fourier transform
`fft2`	Two-dimensional discrete Fourier transform
`fftn`	N-dimensional discrete Fourier Transform
`fftshift`	Shift DC component of discrete Fourier transform to center of spectrum
`ifft`	Inverse one-dimensional discrete Fourier transform
`ifft2`	Inverse two-dimensional discrete Fourier transform
`ifftn`	Inverse multidimensional discrete Fourier transform
`ifftshift`	Inverse fast Fourier transform shift
`nextpow2`	Next power of two
`unwrap`	Correct phase angles

Polynomials

`conv`	Convolution and polynomial multiplication
`deconv`	Deconvolution and polynomial division
`poly`	Polynomial with specified roots
`polyder`	Polynomial derivative
`polyeig`	Polynomial eigenvalue problem
`polyfit`	Polynomial curve fitting
`polyint`	Analytic polynomial integration
`polyval`	Polynomial evaluation
`polyvalm`	Matrix polynomial evaluation
`residue`	Convert between partial fraction expansion and polynomial

	coefficients
`roots`	Polynomial roots

Interpolation and Computational Geometry

- "Interpolation"
- "Delaunay Triangulation and Tessellation"
- "Convex Hull"
- "Voronoi Diagrams"
- "Domain Generation"

Interpolation

`dsearch`	Search for nearest point
`dsearchn`	Multidimensional closest point search
`griddata`	Data gridding
`griddata3`	Data gridding and hypersurface fitting for three-dimensional data
`griddatan`	Data gridding and hypersurface fitting (dimension >= 2)
`interp1`	One-dimensional data interpolation (table lookup)
`interp2`	Two-dimensional data interpolation (table lookup)
`interp3`	Three-dimensional data interpolation (table lookup)
`interpft`	One-dimensional interpolation using fast Fourier transform method
`interpn`	Multidimensional data interpolation (table lookup)
`meshgrid`	Generate X and Y matrices for three-dimensional plots
`mkpp`	Make piecewise polynomial
`ndgrid`	Generate arrays for multidimensional functions and interpolation
`pchip`	Piecewise Cubic Hermite Interpolating Polynomial (PCHIP)
`ppval`	Piecewise polynomial evaluation
`spline`	Cubic spline data interpolation
`tsearchn`	Multidimensional closest simplex search
`unmkpp`	Piecewise polynomial details

Delaunay Triangulation and Tessellation

`delaunay`	Delaunay triangulation
`delaunay3`	Three-dimensional Delaunay tessellation
`delaunayn`	Multidimensional Delaunay tessellation
`dsearch`	Search for nearest point
`dsearchn`	Multidimensional closest point search

`tetramesh`	Tetrahedron mesh plot
`trimesh`	Triangular mesh plot
`triplot`	Two-dimensional triangular plot
`trisurf`	Triangular surface plot
`tsearch`	Search for enclosing Delaunay triangle
`tsearchn`	Multidimensional closest simplex search

Convex Hull

`convhull`	Convex hull
`convhulln`	Multidimensional convex hull
`patch`	Create patch graphics object
`plot`	Linear two-dimensional plot
`trisurf`	Triangular surface plot

Voronoi Diagrams

`dsearch`	Search for nearest point
`patch`	Create patch graphics object
`plot`	Linear two-dimensional plot
`voronoi`	Voronoi diagram
`voronoin`	Multidimensional Voronoi diagrams

Domain Generation

`meshgrid`	Generate X and Y matrices for three-dimensional plots
`ndgrid`	Generate arrays for multidimensional functions and interpolation

Coordinate System Conversion

Cartesian

`cart2sph`	Transform Cartesian to spherical coordinates
`cart2pol`	Transform Cartesian to polar coordinates
`pol2cart`	Transform polar to Cartesian coordinates
`sph2cart`	Transform spherical to Cartesian coordinates

Nonlinear Numerical Methods

- "Ordinary Differential Equations (IVP)"
- "Delay Differential Equations"
- "Boundary Value Problems"

- “Partial Differential Equations”
- “Optimization”
- “Numerical Integration (Quadrature)”

Ordinary Differential Equations (IVP)

`deval`	Evaluate solution of differential equation problem
`ode113`	Solve non-stiff differential equations, variable order method
`ode15s`	Solve stiff ODEs and DAEs Index 1, variable order method
`ode23`	Solve non-stiff differential equations, low order method
`ode23s`	Solve stiff differential equations, low order method
`ode23t`	Solve moderately stiff ODEs and DAEs Index 1, trapezoidal rule
`ode23tb`	Solve stiff differential equations, low order method
`ode45`	Solve non-stiff differential equations, medium order method
`odeget`	Get ODE options parameters
`odeset`	Create/alter ODE `options` structure

Delay Differential Equations

`dde23`	Solve delay differential equations with constant delays
`ddeget`	Get DDE options parameters
`ddeset`	Create/alter DDE `options` structure

Boundary Value Problems

`bvp4c`	Solve two-point boundary value problems for ODEs by collocation
`bvpget`	Get BVP options parameters
`bvpset`	Create/alter BVP `options` structure
`deval`	Evaluate solution of differential equation problem

Partial Differential Equations

`pdepe`	Solve initial-boundary value problems for parabolic-elliptic PDEs
`pdeval`	Evaluates by interpolation solution computed by `pdepe`

Optimization

`fminbnd`	Scalar bounded nonlinear function minimization
`fminsearch`	Multidimensional unconstrained nonlinear minimization, by Nelder-Mead direct search method
`fzero`	Scalar nonlinear zero finding
`lsqnonneg`	Linear least squares with nonnegativity constraints

`optimset`	Create or alter optimization `options` structure
`optimget`	Get optimization parameters from `options` structure

Numerical Integration (Quadrature)

`quad`	Numerically evaluate integral, adaptive Simpson quadrature (low order)
`quadl`	Numerically evaluate integral, adaptive Lobatto quadrature (high order)
`dblquad`	Numerically evaluate double integral
`triplequad`	Numerically evaluate triple integral

Specialized Math

`airy`	Airy functions
`besselh`	Bessel functions of third kind (Hankel functions)
`besseli`	Modified Bessel function of first kind
`besselj`	Bessel function of first kind
`besselk`	Modified Bessel function of second kind
`bessely`	Bessel function of second kind
`beta`	Beta function
`betainc`	Incomplete beta function
`betaln`	Logarithm of beta function
`ellipj`	Jacobi elliptic functions
`ellipke`	Complete elliptic integrals of first and second kind
`erf`	Error function
`erfc`	Complementary error function
`erfcinv`	Inverse complementary error function
`erfcx`	Scaled complementary error function
`erfinv`	Inverse error function
`expint`	Exponential integral
`gamma`	Gamma function
`gammainc`	Incomplete gamma function
`gammaln`	Logarithm of gamma function
`legendre`	Associated Legendre functions
`psi`	Psi (polygamma) function

Sparse Matrices

- “Elementary Sparse Matrices”
- “Full to Sparse Conversion”
- “Working with Sparse Matrices”

- “Reordering Algorithms”
- “Linear Algebra”
- “Linear Equations (Iterative Methods)”
- “Tree Operations”

Elementary Sparse Matrices

`spdiags`	Sparse matrix formed from diagonals
`speye`	Sparse identity matrix
`sprand`	Sparse uniformly distributed random matrix
`sprandn`	Sparse normally distributed random matrix
`sprandsym`	Sparse random symmetric matrix

Full to Sparse Conversion

`find`	Find indices of nonzero elements
`full`	Convert sparse matrix to full matrix
`sparse`	Create sparse matrix
`spconvert`	Import from sparse matrix external format

Working with Sparse Matrices

`issparse`	True for sparse matrix
`nnz`	Number of nonzero matrix elements
`nonzeros`	Nonzero matrix elements
`nzmax`	Amount of storage allocated for nonzero matrix elements
`spalloc`	Allocate space for sparse matrix
`spfun`	Apply function to nonzero matrix elements
`spones`	Replace nonzero sparse matrix elements with ones
`spparms`	Set parameters for sparse matrix routines
`spy`	Visualize sparsity pattern

Reordering Algorithms

`colamd`	Column approximate minimum degree permutation
`colmmd`	Column minimum degree permutation
`colperm`	Column permutation
`dmperm`	Dulmage-Mendelsohn permutation
`randperm`	Random permutation
`symamd`	Symmetric approximate minimum degree permutation
`symmmd`	Symmetric minimum degree permutation
`symrcm`	Symmetric reverse Cuthill-McKee permutation

Linear Algebra

`cholinc`	Incomplete Cholesky factorization
`condest`	1-norm condition number estimate
`eigs`	Eigenvalues and eigenvectors of sparse matrix
`luinc`	Incomplete LU factorization
`normest`	Estimate matrix 2-norm
`sprank`	Structural rank
`svds`	Singular values and vectors of sparse matrix

Linear Equations (Iterative Methods)

`bicg`	BiConjugate Gradients method
`bicgstab`	BiConjugate Gradients Stabilized method
`cgs`	Conjugate Gradients Squared method
`gmres`	Generalized Minimum Residual method
`lsqr`	LSQR implementation of Conjugate Gradients on Normal Equations
`minres`	Minimum Residual method
`pcg`	Preconditioned Conjugate Gradients method
`qmr`	Quasi-Minimal Residual method
`spaugment`	Form least squares augmented system
`symmlq`	Symmetric LQ method

Tree Operations

`etree`	Elimination tree
`etreeplot`	Plot elimination tree
`gplot`	Plot graph, as in “graph theory”
`symbfact`	Symbolic factorization analysis
`treelayout`	Lay out tree or forest
`treeplot`	Plot picture of tree

Math Constants

`eps`	Floating-point relative accuracy
`i`	Imaginary unit
`Inf`	Infinity, ∞
`j`	Imaginary unit
`NaN`	Not-a-Number
`pi`	Ratio of a circle’s circumference to its diameter, π
`realmax`	Largest positive floating-point number
`realmin`	Smallest positive floating-point number

Programming and Data Types

Functions to store and operate on data at either the MATLAB command line or in programs and scripts. Functions to write, manage, and execute MATLAB programs.

"Data Types"	Numeric, character, structures, cell arrays, and data type conversion
"Arrays"	Basic array operations and manipulation
"Operators and Operations"	Special characters and arithmetic, bit-wise, relational, logical, set, date and time operations
"Programming in MATLAB"	M-files, function/expression evaluation, program control, function handles, object oriented programming, error handling

Data Types

- "Numeric"
- "Characters and Strings"
- "Structures"
- "Cell Arrays"
- "Data Type Conversion"
- "Determine Data Type"

Numeric

`[ ]`	Array constructor
`cat`	Concatenate arrays
`class`	Return object's class name (e.g., numeric)
`find`	Find indices and values of nonzero array elements
`ipermute`	Inverse permute dimensions of multidimensional array
`isa`	Detect object of given class (e.g., numeric)
`isequal`	Determine if arrays are numerically equal
`isequalwithequalnans`	Test for equality, treating `NaN`s as equal
`isnumeric`	Determine if item is numeric array
`isreal`	Determine if all array elements are real numbers
`permute`	Rearrange dimensions of multidimensional array

`reshape`	Reshape array
`squeeze`	Remove singleton dimensions from array
`zeros`	Create array of all zeros

Characters and Strings

Description of Strings in MATLAB

`strings`	Describes MATLAB string handling

Creating and Manipulating Strings

`blanks`	Create string of blanks
`char`	Create character array (string)
`cellstr`	Create cell array of strings from character array
`datestr`	Convert to date string format
`deblank`	Strip trailing blanks from the end of string
`lower`	Convert string to lower case
`sprintf`	Write formatted data to string
`sscanf`	Read string under format control
`strcat`	String concatenation
`strjust`	Justify character array
`strread`	Read formatted data from string
`strrep`	String search and replace
`strvcat`	Vertical concatenation of strings
`upper`	Convert string to upper case

Comparing and Searching Strings

`class`	Return object's class name (e.g., char)
`findstr`	Find string within another, longer string
`isa`	Detect object of given class (e.g., char)
`iscellstr`	Determine if item is cell array of strings
`ischar`	Determine if item is character array
`isletter`	Detect array elements that are letters of the alphabet
`isspace`	Detect elements that are ASCII white spaces
`regexp`	Match regular expression
`regexpi`	Match regular expression, ignoring case
`regexprep`	Replace string using regular expression
`strcmp`	Compare strings
`strcmpi`	Compare strings, ignoring case
`strfind`	Find one string within another
`strmatch`	Find possible matches for string
`strncmp`	Compare first `n` characters of strings

`strncmpi`	Compare first n characters of strings, ignoring case
`strtok`	First token in string

Evaluating String Expressions

`eval`	Execute string containing MATLAB expression
`evalc`	Evaluate MATLAB expression with capture
`evalin`	Execute string containing MATLAB expression in workspace

Structures

`cell2struct`	Cell array to structure array conversion
`class`	Return object's class name (e.g., struct)
`deal`	Deal inputs to outputs
`fieldnames`	Field names of structure
`isa`	Detect object of given class (e.g., struct)
`isequal`	Determine if arrays are numerically equal
`isfield`	Determine if item is structure array field
`isstruct`	Determine if item is structure array
`orderfields`	Order fields of a structure array
`rmfield`	Remove structure fields
`struct`	Create structure array
`struct2cell`	Structure to cell array conversion

Cell Arrays

`{ }`	Construct cell array
`cell`	Construct cell array
`cellfun`	Apply function to each element in cell array
`cellstr`	Create cell array of strings from character array
`cell2mat`	Convert cell array of matrices into single matrix
`cell2struct`	Cell array to structure array conversion
`celldisp`	Display cell array contents
`cellplot`	Graphically display structure of cell arrays
`class`	Return object's class name (e.g., cell)
`deal`	Deal inputs to outputs
`isa`	Detect object of given class (e.g., cell)
`iscell`	Determine if item is cell array
`iscellstr`	Determine if item is cell array of strings
`isequal`	Determine if arrays are numerically equal
`mat2cell`	Divide matrix up into cell array of matrices
`num2cell`	Convert numeric array into cell array
`struct2cell`	Structure to cell array conversion

Data Type Conversion

Numeric

`double`	Convert to double-precision
`int8`	Convert to signed 8-bit integer
`int16`	Convert to signed 16-bit integer
`int32`	Convert to signed 32-bit integer
`int64`	Convert to signed 64-bit integer
`single`	Convert to single-precision
`uint8`	Convert to unsigned 8-bit integer
`uint16`	Convert to unsigned 16-bit integer
`uint32`	Convert to unsigned 32-bit integer
`uint64`	Convert to unsigned 64-bit integer

String to Numeric

`base2dec`	Convert base `N` number string to decimal number
`bin2dec`	Convert binary number string to decimal number
`hex2dec`	Convert hexadecimal number string to decimal number
`hex2num`	Convert hexadecimal number string to double number
`str2double`	Convert string to double-precision number
`str2num`	Convert string to number

Numeric to String

`char`	Convert to character array (string)
`dec2base`	Convert decimal to base `N` number in string
`dec2bin`	Convert decimal to binary number in string
`dec2hex`	Convert decimal to hexadecimal number in string
`int2str`	Convert integer to string
`mat2str`	Convert a matrix to string
`num2str`	Convert number to string

Other Conversions

`cell2mat`	Convert cell array of matrices into single matrix
`cell2struct`	Convert cell array to structure array
`datestr`	Convert serial date number to string
`func2str`	Convert function handle to function name string
`logical`	Convert numeric to logical array
`mat2cell`	Divide matrix up into cell array of matrices
`num2cell`	Convert a numeric array to cell array
`str2func`	Convert function name string to function handle
`struct2cell`	Convert structure to cell array

Determine Data Type

`is*`	Detect state
`isa`	Detect object of given MATLAB class or Java class
`iscell`	Determine if item is cell array
`iscellstr`	Determine if item is cell array of strings
`ischar`	Determine if item is character array
`isfield`	Determine if item is character array
`isjava`	Determine if item is Java object
`islogical`	Determine if item is logical array
`isnumeric`	Determine if item is numeric array
`isobject`	Determine if item is MATLAB OOPs object
`isstruct`	Determine if item is MATLAB structure array

Arrays

- "Array Operations"
- "Basic Array Information"
- "Array Manipulation"
- "Elementary Arrays"

Array Operations

`[ ]`	Array constructor
`,`	Array row element separator
`;`	Array column element separator
`:`	Specify range of array elements
`end`	Indicate last index of array
`+`	Addition or unary plus
`-`	Subtraction or unary minus
`.*`	Array multiplication
`./`	Array right division
`.\`	Array left division
`.^`	Array power
`.'`	Array (nonconjugated) transpose

Basic Array Information

`disp`	Display text or array
`display`	Overloaded method to display text or array
`isempty`	Determine if array is empty
`isequal`	Determine if arrays are numerically equal
`isequalwithequalnans`	Test for equality, treating `NaN`s as equal

`isnumeric`	Determine if item is numeric array
`islogical`	Determine if item is logical array
`length`	Length of vector
`ndims`	Number of array dimensions
`numel`	Number of elements in matrix or cell array
`size`	Array dimensions

Array Manipulation

`:`	Specify range of array elements
`blkdiag`	Construct block diagonal matrix from input arguments
`cat`	Concatenate arrays
`circshift`	Shift array circularly
`find`	Find indices and values of nonzero elements
`fliplr`	Flip matrices left-right
`flipud`	Flip matrices up-down
`flipdim`	Flip array along specified dimension
`horzcat`	Horizontal concatenation
`ind2sub`	Subscripts from linear index
`ipermute`	Inverse permute dimensions of multidimensional array
`permute`	Rearrange dimensions of multidimensional array
`repmat`	Replicate and tile array
`reshape`	Reshape array
`rot90`	Rotate matrix 90 degrees
`shiftdim`	Shift dimensions
`sort`	Sort elements in ascending order
`sortrows`	Sort rows in ascending order
`squeeze`	Remove singleton dimensions
`sub2ind`	Single index from subscripts
`vertcat`	Horizontal concatenation

Elementary Arrays

`:`	Regularly spaced vector
`blkdiag`	Construct block diagonal matrix from input arguments
`eye`	Identity matrix
`linspace`	Generate linearly spaced vectors
`logspace`	Generate logarithmically spaced vectors
`meshgrid`	Generate X and Y matrices for three-dimensional plots
`ndgrid`	Generate arrays for multidimensional functions and interpolation
`ones`	Create array of all ones
`rand`	Uniformly distributed random numbers and arrays
`randn`	Normally distributed random numbers and arrays
`zeros`	Create array of all zeros

Operators and Operations

Special Characters

`:`	Specify range of array elements
`( )`	Pass function arguments, or prioritize operations
`[ ]`	Construct array
`{ }`	Construct cell array
`.`	Decimal point, or structure field separator
`...`	Continue statement to next line
`,`	Array row element separator
`;`	Array column element separator
`%`	Insert comment line into code
`!`	Command to operating system
`=`	Assignment

Arithmetic Operations

`+`	Plus
`-`	Minus
`.`	Decimal point
`=`	Assignment
`*`	Matrix multiplication
`/`	Matrix right division
`\`	Matrix left division
`^`	Matrix power
`'`	Matrix transpose
`.*`	Array multiplication (element-wise)
`./`	Array right division (element-wise)
`.\`	Array left division (element-wise)
`.^`	Array power (element-wise)
`.'`	Array transpose

Bit-wise Operations

bitand	Bit-wise AND
bitcmp	Bit-wise complement
bitor	Bit-wise OR
bitmax	Maximum floating-point integer
bitset	Set bit at specified position
bitshift	Bit-wise shift
bitget	Get bit at specified position
bitxor	Bit-wise XOR

Relational Operations

<	Less than
<=	Less than or equal to
>	Greater than
>=	Greater than or equal to
==	Equal to
~=	Not equal to

Logical Operations

&&	Logical AND
||	Logical OR
&	Logical AND for arrays
|	Logical OR for arrays
~	Logical NOT
all	Test to determine if all elements are nonzero
any	Test for any nonzero elements
false	False array
find	Find indices and values of nonzero elements
is*	Detect state
isa	Detect object of given class
iskeyword	Determine if string is MATLAB keyword
isvarname	Determine if string is valid variable name
logical	Convert numeric values to logical
true	True array
xor	Logical EXCLUSIVE OR

Set Operations

intersect	Set intersection of two vectors
ismember	Detect members of set
setdiff	Return set difference of two vectors
issorted	Determine if set elements are in sorted order

`setxor`	Set exclusive or of two vectors
`union`	Set union of two vectors
`unique`	Unique elements of vector

Date and Time Operations

`calendar`	Calendar for specified month
`clock`	Current time as date vector
`cputime`	Elapsed CPU time
`date`	Current date string
`datenum`	Serial date number
`datestr`	Convert serial date number to string
`datevec`	Date components
`eomday`	End of month
`etime`	Elapsed time
`now`	Current date and time
`tic, toc`	Stopwatch timer
`weekday`	Day of the week

Programming in MATLAB

- "M-File Functions and Scripts"
- "Evaluation of Expressions and Functions"
- "Timer Functions"
- "Variables and Functions in Memory"
- "Control Flow"
- "Function Handles"
- "Object-Oriented Programming"
- "Error Handling"
- "MEX Programming"

M-File Functions and Scripts

`( )`	Pass function arguments
`%`	Insert comment line into code
`...`	Continue statement to next line
`depfun`	List dependent functions of M-file or P-file
`depdir`	List dependent directories of M-file or P-file
`function`	Function M-files
`input`	Request user input

`inputname`	Input argument name
`mfilename`	Name of currently running M-file
`namelengthmax`	Return maximum identifier length
`nargin`	Number of function input arguments
`nargout`	Number of function output arguments
`nargchk`	Check number of input arguments
`nargoutchk`	Validate number of output arguments
`pcode`	Create preparsed pseudocode file (P-file)
`script`	Describes script M-file
`varargin`	Accept variable number of arguments
`varargout`	Return variable number of arguments

Evaluation of Expressions and Functions

`builtin`	Execute builtin function from overloaded method
`cellfun`	Apply function to each element in cell array
`eval`	Interpret strings containing MATLAB expressions
`evalc`	Evaluate MATLAB expression with capture
`evalin`	Evaluate expression in workspace
`feval`	Evaluate function
`iskeyword`	Determine if item is MATLAB keyword
`isvarname`	Determine if item is valid variable name
`pause`	Halt execution temporarily
`run`	Run script that is not on current path
`script`	Describes script M-file
`symvar`	Determine symbolic variables in expression
`tic`, `toc`	Stopwatch timer

Timer Functions

`delete`	Delete timer object from memory
`disp`	Display information about timer object
`get`	Retrieve information about timer object properties
`isvalid`	Determine if timer object is valid
`set`	Display or set timer object properties
`start`	Start a timer
`startat`	Start a timer at a specific timer
`stop`	Stop a timer
`timer`	Create a timer object
`timerfind`	Return an array of all timer object in memory
`wait`	Block command line until timer completes

Variables and Functions in Memory

`assignin`	Assign value to workspace variable

`global`	Define global variables
`inmem`	Return names of functions in memory
`isglobal`	Determine if item is global variable
`mislocked`	True if M-file cannot be cleared
`mlock`	Prevent clearing M-file from memory
`munlock`	Allow clearing M-file from memory
`namelengthmax`	Return maximum identifier length
`pack`	Consolidate workspace memory
`persistent`	Define persistent variable
`rehash`	Refresh function and file system caches

Control Flow

`break`	Terminate execution of `for` loop or `while` loop
`case`	Case switch
`catch`	Begin catch block
`continue`	Pass control to next iteration of `for` or `while` loop
`else`	Conditionally execute statements
`elseif`	Conditionally execute statements
`end`	Terminate conditional statements, or indicate last index
`error`	Display error messages
`for`	Repeat statements specific number of times
`if`	Conditionally execute statements
`otherwise`	Default part of `switch` statement
`return`	Return to invoking function
`switch`	Switch among several cases based on expression
`try`	Begin `try` block
`while`	Repeat statements indefinite number of times

Function Handles

`class`	Return object's class name (e.g. function_handle)
`feval`	Evaluate function
`function_handle`	Describes function handle data type
`functions`	Return information about function handle
`func2str`	Constructs function name string from function handle
`isa`	Detect object of given class (e.g. function_handle)
`isequal`	Determine if function handles are equal
`str2func`	Constructs function handle from function name string

Object-Oriented Programming

MATLAB Classes and Objects

`class`	Create object or return class of object
`fieldnames`	List public fields belonging to object,
`inferiorto`	Establish inferior class relationship
`isa`	Detect object of given class
`isobject`	Determine if item is MATLAB OOPs object
`loadobj`	User-defined extension of `load` function for user objects
`methods`	Display method names
`methodsview`	Displays information on all methods implemented by class
`saveobj`	User-defined extension of `save` function for user objects
`subsasgn`	Overloaded method for `A(I)=B`, `A{I}=B`, and `A.field=B`
`subsindex`	Overloaded method for `X(A)`
`subsref`	Overloaded method for `A(I)`, `A{I}` and `A.field`
`substruct`	Create structure argument for subsasgn or subsref
`superiorto`	Establish superior class relationship

Java Classes and Objects

`cell`	Convert Java array object to cell array
`class`	Return class name of Java object
`clear`	Clear Java packages import list
`depfun`	List Java classes used by M-file
`exist`	Detect if item is Java class
`fieldnames`	List public fields belonging to object
`im2java`	Convert image to instance of Java image object
`import`	Add package or class to current Java import list
`inmem`	List names of Java classes loaded into memory
`isa`	Detect object of given class
`isjava`	Determine whether object is Java object
`javaArray`	Constructs Java array
`javaMethod`	Invokes Java method
`javaObject`	Constructs Java object
`methods`	Display methods belonging to class
`methodsview`	Display information on all methods implemented by class
`which`	Display package and class name for method

Error Handling

`catch`	Begin `catch` block of `try/catch` statement
`error`	Display error message
`ferror`	Query MATLAB about errors in file input or output

`lasterr`	Return last error message generated by MATLAB
`lasterror`	Last error message and related information
`lastwarn`	Return last warning message issued by MATLAB
`rethrow`	Reissue error
`try`	Begin `try` block of `try/catch` statement
`warning`	Display warning message

MEX Programming

`dbmex`	Enable MEX-file debugging
`inmem`	Return names of currently loaded MEX-files
`mex`	Compile MEX-function from C or Fortran source code
`mexext`	Return MEX-filename extension

File I/O

Functions to read and write data to files of different format types.

"Filename Construction"	Get path, directory, filename information; construct filenames
"Opening, Loading, Saving Files"	Open files; transfer data between files and MATLAB workspace
"Low-Level File I/O"	Low-level operations that use a file identifier (e.g., fopen, fseek, fread)
"Text Files"	Delimited or formatted I/O to text files
"XML Documents"	Documents written in Extensible Markup Language
"Spreadsheets"	Excel and Lotus 123 files
"Scientific Data"	CDF, FITS, HDF formats
"Audio and Audio/Video"	General audio functions; SparcStation, Wave, AVI files
"Images"	Graphics files

To see a listing of file formats that are readable from MATLAB, go to `file formats`.

Filename Construction

`fileparts`	Return parts of filename
`filesep`	Return directory separator for this platform
`fullfile`	Build full filename from parts
`tempdir`	Return name of system's temporary directory
`tempname`	Return unique string for use as temporary filename

Opening, Loading, Saving Files

`importdata`	Load data from various types of files
`load`	Load all or specific data from MAT or ASCII file
`open`	Open files of various types using appropriate editor or program
`save`	Save all or specific data to MAT or ASCII file
`winopen`	Open file in appropriate application (Windows only)

Low-Level File I/O

`fclose`	Close one or more open files
`feof`	Test for end-of-file
`ferror`	Query MATLAB about errors in file input or output
`fgetl`	Return next line of file as string without line terminator(s)
`fgets`	Return next line of file as string with line terminator(s)
`fopen`	Open file or obtain information about open files
`fprintf`	Write formatted data to file
`fread`	Read binary data from file
`frewind`	Rewind open file
`fscanf`	Read formatted data from file
`fseek`	Set file position indicator
`ftell`	Get file position indicator
`fwrite`	Write binary data to file

Text Files

`csvread`	Read numeric data from text file, using comma delimiter
`csvwrite`	Write numeric data to text file, using comma delimiter
`dlmread`	Read numeric data from text file, specifying your own delimiter
`dlmwrite`	Write numeric data to text file, specifying your own delimiter
`textread`	Read data from text file, specifying format for each value

XML Documents

`xmlread`	Parse XML document
`xmlwrite`	Serialize XML Document Object Model node
`xslt`	Transform XML document using XSLT engine

Spreadsheets

Microsoft Excel Functions

`xlsfinfo`	Determine if file contains Microsoft Excel (`.xls`) spreadsheet
`xlsread`	Read Microsoft Excel spreadsheet file (`.xls`)

Lotus123 Functions

`wk1read`	Read Lotus123 WK1 spreadsheet file into matrix
`wk1write`	Write matrix to Lotus123 WK1 spreadsheet file

Scientific Data

Common Data Format (CDF)

`cdfinfo`	Return information about CDF file
`cdfread`	Read CDF file

Flexible Image Transport System

`fitsinfo`	Return information about FITS file
`fitsread`	Read FITS file

Hierarchical Data Format (HDF)

`hdf`	Interface to HDF files
`hdfinfo`	Return information about HDF or HDF-EOS file
`hdfread`	Read HDF file

Audio and Audio/Video

General

`audioplayer`	Create audio player object
`audiorecorder`	Perform real-time audio capture
`beep`	Produce beep sound
`lin2mu`	Convert linear audio signal to mu-law
`mu2lin`	Convert mu-law audio signal to linear
`sound`	Convert vector into sound
`soundsc`	Scale data and play as sound

SPARCstation-Specific Sound Functions

`auread`	Read NeXT/SUN (`.au`) sound file
`auwrite`	Write NeXT/SUN (`.au`) sound file

Microsoft WAVE Sound Functions

`wavplay`	Play sound on PC-based audio output device
`wavread`	Read Microsoft WAVE (`.wav`) sound file
`wavrecord`	Record sound using PC-based audio input device
`wavwrite`	Write Microsoft WAVE (`.wav`) sound file

Audio Video Interleaved (AVI) Functions

`addframe`	Add frame to AVI file
`avifile`	Create new AVI file
`aviinfo`	Return information about AVI file
`aviread`	Read AVI file
`close`	Close AVI file
`movie2avi`	Create AVI movie from MATLAB movie

Images

`im2java`	Convert image to instance of Java image object
`imfinfo`	Return information about graphics file
`imread`	Read image from graphics file
`imwrite`	Write image to graphics file

Graphics

2-D graphs, specialized plots (e.g., pie charts, histograms, and contour plots), function plotters, and Handle Graphics functions.

Basic Plots and Graphs	Linear line plots, log and semilog plots
Annotating Plots	Titles, axes labels, legends, mathematical symbols
Specialized Plotting	Bar graphs, histograms, pie charts, contour plots, function plotters
Bit-Mapped Images	Display image object, read and write graphics file, convert to movie frames
Printing	Printing and exporting figures to standard formats
Handle Graphics	Creating graphics objects, setting properties, finding handles

Basic Plots and Graphs

`box`	Axis box for 2-D and 3-D plots
`errorbar`	Plot graph with error bars
`hold`	Hold current graph
`LineSpec`	Line specification syntax
`loglog`	Plot using log-log scales
`polar`	Polar coordinate plot
`plot`	Plot vectors or matrices.
`plot3`	Plot lines and points in 3-D space
`plotyy`	Plot graphs with Y tick labels on the left and right
`semilogx`	Semi-log scale plot
`semilogy`	Semi-log scale plot
`subplot`	Create axes in tiled positions

Annotating Plots

`clabel`	Add contour labels to contour plot
`datetick`	Date formatted tick labels
`gtext`	Place text on 2-D graph using mouse
`legend`	Graph legend for lines and patches
`texlabel`	Produce the TeX format from character string

`title`	Titles for 2-D and 3-D plots
`xlabel`	X-axis labels for 2-D and 3-D plots
`ylabel`	Y-axis labels for 2-D and 3-D plots
`zlabel`	Z-axis labels for 3-D plots

Specialized Plotting

- “Area, Bar, and Pie Plots”
- “Contour Plots”
- “Direction and Velocity Plots”
- “Discrete Data Plots”
- “Function Plots”
- “Histograms”
- “Polygons and Surfaces”
- “Scatter Plots”
- “Animation”

Area, Bar, and Pie Plots

`area`	Area plot
`bar`	Vertical bar chart
`barh`	Horizontal bar chart
`bar3`	Vertical 3-D bar chart
`bar3h`	Horizontal 3-D bar chart
`pareto`	Pareto char
`pie`	Pie plot
`pie3`	3-D pie plot

Contour Plots

`contour`	Contour (level curves) plot
`contour3`	3-D contour plot
`contourc`	Contour computation
`contourf`	Filled contour plot
`ezcontour`	Easy to use contour plotter
`ezcontourf`	Easy to use filled contour plotter

Direction and Velocity Plots

`comet`	Comet plot
`comet3`	3-D comet plot

`compass`	Compass plot
`feather`	Feather plot
`quiver`	Quiver (or velocity) plot
`quiver3`	3-D quiver (or velocity) plot

Discrete Data Plots

`stem`	Plot discrete sequence data
`stem3`	Plot discrete surface data
`stairs`	Stairstep graph

Function Plots

`ezcontour`	Easy to use contour plotter
`ezcontourf`	Easy to use filled contour plotter
`ezmesh`	Easy to use 3-D mesh plotter
`ezmeshc`	Easy to use combination mesh/contour plotter
`ezplot`	Easy to use function plotter
`ezplot3`	Easy to use 3-D parametric curve plotter
`ezpolar`	Easy to use polar coordinate plotter
`ezsurf`	Easy to use 3-D colored surface plotter
`ezsurfc`	Easy to use combination surface/contour plotter
`fplot`	Plot a function

Histograms

`hist`	Plot histograms
`histc`	Histogram count
`rose`	Plot rose or angle histogram

Polygons and Surfaces

`convhull`	Convex hull
`cylinder`	Generate cylinder
`delaunay`	Delaunay triangulation
`dsearch`	Search Delaunay triangulation for nearest point
`ellipsoid`	Generate ellipsoid
`fill`	Draw filled 2-D polygons
`fill3`	Draw filled 3-D polygons in 3-space
`inpolygon`	True for points inside a polygonal region
`pcolor`	Pseudocolor (checkerboard) plot
`polyarea`	Area of polygon
`ribbon`	Ribbon plot
`slice`	Volumetric slice plot
`sphere`	Generate sphere

`tsearch`	Search for enclosing Delaunay triangle
`voronoi`	Voronoi diagram
`waterfall`	Waterfall plot

Scatter Plots

`plotmatrix`	Scatter plot matrix
`scatter`	Scatter plot
`scatter3`	3-D scatter plot

Animation

`frame2im`	Convert movie frame to indexed image
`getframe`	Capture movie frame
`im2frame`	Convert image to movie frame
`movie`	Play recorded movie frames
`noanimate`	Change `EraseMode` of all objects to `normal`

Bit-Mapped Images

`frame2im`	Convert movie frame to indexed image
`image`	Display image object
`imagesc`	Scale data and display image object
`imfinfo`	Information about graphics file
`imformats`	Manage file format registry
`im2frame`	Convert image to movie frame
`im2java`	Convert image to instance of Java image object
`imread`	Read image from graphics file
`imwrite`	Write image to graphics file
`ind2rgb`	Convert indexed image to RGB image

Printing

`frameedit`	Edit print frame for Simulink and Stateflow diagram
`orient`	Hardcopy paper orientation
`pagesetupdlg`	Page position dialog box
`print`	Print graph or save graph to file
`printdlg`	Print dialog box
`printopt`	Configure local printer defaults
`printpreview`	Preview figure to be printed
`saveas`	Save figure to graphic file

Handle Graphics

- Finding and Identifying Graphics Objects
- Object Creation Functions
- Figure Windows
- Axes Operations

Finding and Identifying Graphics Objects

`allchild`	Find all children of specified objects
`copyobj`	Make copy of graphics object and its children
`delete`	Delete files or graphics objects
`findall`	Find all graphics objects (including hidden handles)
`figflag`	Test if figure is on screen
`findfigs`	Display off-screen visible figure windows
`findobj`	Find objects with specified property values
`gca`	Get current Axes handle
`gcbo`	Return object whose callback is currently executing
`gcbf`	Return handle of figure containing callback object
`gco`	Return handle of current object
`get`	Get object properties
`ishandle`	True if value is valid object handle
`set`	Set object properties

Object Creation Functions

`axes`	Create axes object
`figure`	Create figure (graph) windows
`image`	Create image (2-D matrix)
`light`	Create light object (illuminates Patch and Surface)
`line`	Create line object (3-D polylines)
`patch`	Create patch object (polygons)
`rectangle`	Create rectangle object (2-D rectangle)
`rootobject`	List of root properties
`surface`	Create surface (quadrilaterals)
`text`	Create text object (character strings)
`uicontextmenu`	Create context menu (popup associated with object)

Figure Windows

`capture`	Screen capture of the current figure
`clc`	Clear figure window
`clf`	Clear figure

`close`	Close specified window
`closereq`	Default close request function
`drawnow`	Complete any pending drawing
`figflag`	Test if figure is on screen
`gcf`	Get current figure handle
`hgload`	Load graphics object hierarchy from a FIG-file
`hgsave`	Save graphics object hierarchy to a FIG-file
`newplot`	Graphics M-file preamble for `NextPlot` property
`opengl`	Change automatic selection mode of OpenGL rendering
`refresh`	Refresh figure
`saveas`	Save figure or model to desired output format

Axes Operations

`axis`	Plot axis scaling and appearance
`box`	Display axes border
`cla`	Clear Axes
`gca`	Get current Axes handle
`grid`	Grid lines for 2-D and 3-D plots
`ishold`	Get the current hold state

3-D Visualization

Create and manipulate graphics that display 2-D matrix and 3-D volume data, controlling the view, lighting and transparency.

Surface and Mesh Plots	Plot matrices, visualize functions of two variables, specify colormap
View Control	Control the camera viewpoint, zooming, rotation, aspect ratio, set axis limits
Lighting	Add and control scene lighting
Transparency	Specify and control object transparency
Volume Visualization	Visualize gridded volume data

Surface and Mesh Plots

- Creating Surfaces and Meshes
- Domain Generation
- Color Operations
- Colormaps

Creating Surfaces and Meshes

`hidden`	Mesh hidden line removal mode
`meshc`	Combination mesh/contourplot
`mesh`	3-D mesh with reference plane
`peaks`	A sample function of two variables
`surf`	3-D shaded surface graph
`surface`	Create surface low-level objects
`surfc`	Combination surf/contourplot
`surfl`	3-D shaded surface with lighting
`tetramesh`	Tetrahedron mesh plot
`trimesh`	Triangular mesh plot
`triplot`	2-D triangular plot
`trisurf`	Triangular surface plot

Domain Generation

`griddata`	Data gridding and surface fitting
`meshgrid`	Generation of X and Y arrays for 3-D plots

Color Operations

`brighten`	Brighten or darken color map
`caxis`	Pseudocolor axis scaling
`colormapeditor`	Start colormap editor
`colorbar`	Display color bar (color scale)
`colordef`	Set up color defaults
`colormap`	Set the color look-up table (list of colormaps)
`ColorSpec`	Ways to specify color
`graymon`	Graphics figure defaults set for grayscale monitor
`hsv2rgb`	Hue-saturation-value to red-green-blue conversion
`rgb2hsv`	RGB to HSVconversion
`rgbplot`	Plot color map
`shading`	Color shading mode
`spinmap`	Spin the colormap
`surfnorm`	3-D surface normals
`whitebg`	Change axes background color for plots

Colormaps

`autumn`	Shades of red and yellow color map
`bone`	Gray-scale with a tinge of blue color map
`contrast`	Gray color map to enhance image contrast
`cool`	Shades of cyan and magenta color map
`copper`	Linear copper-tone color map
`flag`	Alternating red, white, blue, and black color map
`gray`	Linear gray-scale color map
`hot`	Black-red-yellow-white color map
`hsv`	Hue-saturation-value (HSV) color map
`jet`	Variant of HSV
`lines`	Line color colormap
`prism`	Colormap of prism colors
`spring`	Shades of magenta and yellow color map
`summer`	Shades of green and yellow colormap
`winter`	Shades of blue and green color map

View Control

- Controlling the Camera Viewpoint
- Setting the Aspect Ratio and Axis Limits
- Object Manipulation
- Selecting Region of Interest

Controlling the Camera Viewpoint

`camdolly`	Move camera position and target
`camlookat`	View specific objects
`camorbit`	Orbit about camera target
`campan`	Rotate camera target about camera position
`campos`	Set or get camera position
`camproj`	Set or get projection type
`camroll`	Rotate camera about viewing axis
`camtarget`	Set or get camera target
`camup`	Set or get camera up-vector
`camva`	Set or get camera view angle
`camzoom`	Zoom camera in or out
`view`	3-D graph viewpoint specification.
`viewmtx`	Generate view transformation matrices

Setting the Aspect Ratio and Axis Limits

`daspect`	Set or get data aspect ratio
`pbaspect`	Set or get plot box aspect ratio
`xlim`	Set or get the current *x*-axis limits
`ylim`	Set or get the current *y*-axis limits
`zlim`	Set or get the current *z*-axis limits

Object Manipulation

`reset`	Reset axis or figure
`rotate`	Rotate objects about specified origin and direction
`rotate3d`	Interactively rotate the view of a 3-D plot
`selectmoveresize`	Interactively select, move, or resize objects
`zoom`	Zoom in and out on a 2-D plot

Selecting Region of Interest

`dragrect`	Drag XOR rectangles with mouse
`rbbox`	Rubberband box

Lighting

`camlight`	Cerate or position Light
`light`	Light object creation function
`lightangle`	Position light in sphereical coordinates
`lighting`	Lighting mode
`material`	Material reflectance mode

Transparency

`alpha`	Set or query transparency properties for objects in current axes
`alphamap`	Specify the figure alphamap
`alim`	Set or query the axes alpha limits

Volume Visualization

`coneplot`	Plot velocity vectors as cones in 3-D vector field
`contourslice`	Draw contours in volume slice plane
`curl`	Compute curl and angular velocity of vector field
`divergence`	Compute divergence of vector field
`flow`	Generate scalar volume data
`interpstreamspeed`	Interpolate streamline vertices from vector-field magnitudes
`isocaps`	Compute isosurface end-cap geometry
`isocolors`	Compute colors of isosurface vertices
`isonormals`	Compute normals of isosurface vertices
`isosurface`	Extract isosurface data from volume data
`reducepatch`	Reduce number of patch faces
`reducevolume`	Reduce number of elements in volume data set
`shrinkfaces`	Reduce size of patch faces
`slice`	Draw slice planes in volume
`smooth3`	Smooth 3-D data
`stream2`	Compute 2-D stream line data
`stream3`	Compute 3-D stream line data
`streamline`	Draw stream lines from 2- or 3-D vector data
`streamparticles`	Draws stream particles from vector volume data
`streamribbon`	Draws stream ribbons from vector volume data
`streamslice`	Draws well-spaced stream lines from vector volume data
`streamtube`	Draws stream tubes from vector volume data
`surf2patch`	Convert surface data to patch data
`subvolume`	Extract subset of volume data set
`volumebounds`	Return coordinate and color limits for volume (scalar and vector)

Creating Graphical User Interfaces

Predefined dialog boxes and functions to control GUI programs.

Predefined Dialog Boxes	Dialog boxes for error, user input, waiting, etc.
Deploying User Interfaces	Launching GUIs, creating the handles structure
Developing User Interfaces	Starting GUIDE, managing application data, getting user input
User Interface Objects	Creating GUI components
Finding Objects from Callbacks	Finding object handles from within callbacks functions
GUI Utility Functions	Moving objects, text wrapping
Controlling Program Execution	Wait and resume based on user input

Predefined Dialog Boxes

`dialog`	Create dialog box
`errordlg`	Create error dialog box
`helpdlg`	Display help dialog box
`inputdlg`	Create input dialog box
`listdlg`	Create list selection dialog box
`msgbox`	Create message dialog box
`pagedlg`	Display page layout dialog box
`printdlg`	Display print dialog box
`questdlg`	Create question dialog box
`uigetdir`	Display dialog box to retrieve name of directory
`uigetfile`	Display dialog box to retrieve name of file for reading
`uiputfile`	Display dialog box to retrieve name of file for writing
`uisetcolor`	Set `ColorSpec` using dialog box
`uisetfont`	Set font using dialog box
`waitbar`	Display wait bar
`warndlg`	Create warning dialog box

Deploying User Interfaces

`guidata`	Store or retrieve application data
`guihandles`	Create a structure of handles
`movegui`	Move GUI figure onscreen
`openfig`	Open or raise GUI figure

Developing User Interfaces

`guide`	Open GUI Layout Editor
`inspect`	Display Property Inspector

Working with Application Data

`getappdata`	Get value of application data
`isappdata`	True if application data exists
`rmappdata`	Remove application data
`setappdata`	Specify application data

Interactive User Input

`ginput`	Graphical input from a mouse or cursor
`waitfor`	Wait for conditions before resuming execution
`waitforbuttonpress`	Wait for key/buttonpress over figure

User Interface Objects

`menu`	Generate menu of choices for user input
`uicontextmenu`	Create context menu
`uicontrol`	Create user interface control
`uimenu`	Create user interface menu

Finding Objects from Callbacks

`findall`	Find all graphics objects
`findfigs`	Display off-screen visible figure windows
`findobj`	Find specific graphics object
`gcbf`	Return handle of figure containing callback object
`gcbo`	Return handle of object whose callback is executing

GUI Utility Functions

`selectmoveresize`	Select, move, resize, or copy axes and uicontrol graphics objects
`textwrap`	Return wrapped string matrix for given uicontrol

Controlling Program Execution

`uiresume`	Resumes program execution halted with `uiwait`
`uiwait`	Halts program execution, restart with `uiresume`

2

Functions – Alphabetical List

Purpose

Matrix and array arithmetic

Syntax

```
A+B
A-B
A*B      A.*B
A/B      A./B
A\B      A.\B
A^B      A.^B
A'       A.'
```

Description

MATLAB has two different types of arithmetic operations. Matrix arithmetic operations are defined by the rules of linear algebra. Array arithmetic operations are carried out element-by-element, and can be used with multidimensional arrays. The period character (.) distinguishes the array operations from the matrix operations. However, since the matrix and array operations are the same for addition and subtraction, the character pairs `.+` and `.-` are not used.

`+` Addition or unary plus. `A+B` adds `A` and `B`. `A` and `B` must have the same size, unless one is a scalar. A scalar can be added to a matrix of any size.

`-` Subtraction or unary minus. `A-B` subtracts `B` from `A`. `A` and `B` must have the same size, unless one is a scalar. A scalar can be subtracted from a matrix of any size.

`*` Matrix multiplication. `C = A*B` is the linear algebraic product of the matrices `A` and `B`. More precisely,

$$C(i, j) = \sum_{k=1}^{n} A(i, k)B(k, j)$$

For nonscalar `A` and `B`, the number of columns of `A` must equal the number of rows of `B`. A scalar can multiply a matrix of any size.

`.*` Array multiplication. `A.*B` is the element-by-element product of the arrays `A` and `B`. `A` and `B` must have the same size, unless one of them is a scalar.

`/` Slash or matrix right division. `B/A` is roughly the same as `B*inv(A)`. More precisely, `B/A = (A'\B')'`. See `\`.

`./` Array right division. `A./B` is the matrix with elements `A(i,j)/B(i,j)`. `A` and `B` must have the same size, unless one of them is a scalar.

`\` Backslash or matrix left division. If `A` is a square matrix, `A\B` is roughly the same as `inv(A)*B`, except it is computed in a different way. If `A` is an `n`-by-`n` matrix and `B` is a column vector with `n` components, or a matrix with several such columns, then `X = A\B` is the solution to the equation $AX = B$ computed by Gaussian elimination (see “Algorithm” on page 2-15 for details). A warning message prints if `A` is badly scaled or nearly singular.

If `A` is an `m`-by-`n` matrix with `m ~= n` and `B` is a column vector with `m` components, or a matrix with several such columns, then `X = A\B` is the solution in the least squares sense to the under- or overdetermined system of equations $AX = B$. The effective rank, `k`, of `A`, is determined from the QR decomposition with pivoting (see “Algorithm” for details). A solution `X` is computed which has at most `k` nonzero components per column. If `k < n`, this is usually not the same solution as `pinv(A)*B`, which is the least squares solution with the smallest norm, $\|X\|$.

`.\` Array left division. `A.\B` is the matrix with elements `B(i,j)/A(i,j)`. `A` and `B` must have the same size, unless one of them is a scalar.

`^` Matrix power. `X^p` is `X` to the power `p`, if `p` is a scalar. If `p` is an integer, the power is computed by repeated squaring. If the integer is negative, `X` is inverted first. For other values of `p`, the calculation involves eigenvalues and eigenvectors, such that if `[V,D] = eig(X)`, then `X^p = V*D.^p/V`.

If `x` is a scalar and `P` is a matrix, `x^P` is `x` raised to the matrix power `P` using eigenvalues and eigenvectors. `X^P`, where `X` and `P` are both matrices, is an error.

`.^` Array power. `A.^B` is the matrix with elements `A(i,j)` to the `B(i,j)` power. `A` and `B` must have the same size, unless one of them is a scalar.

`'` Matrix transpose. `A'` is the linear algebraic transpose of `A`. For complex matrices, this is the complex conjugate transpose.

`.'` Array transpose. `A.'` is the array transpose of `A`. For complex matrices, this does not involve conjugation.

Remarks

The arithmetic operators have M-file function equivalents, as shown:

Binary addition	`A+B`	`plus(A,B)`
Unary plus	`+A`	`uplus(A)`
Binary subtraction	`A-B`	`minus(A,B)`
Unary minus	`-A`	`uminus(A)`
Matrix multiplication	`A*B`	`mtimes(A,B)`
Array-wise multiplication	`A.*B`	`times(A,B)`
Matrix right division	`A/B`	`mrdivide(A,B)`
Array-wise right division	`A./B`	`rdivide(A,B)`
Matrix left division	`A\B`	`mldivide(A,B)`
Array-wise left division	`A.\B`	`ldivide(A,B)`
Matrix power	`A^B`	`mpower(A,B)`
Array-wise power	`A.^B`	`power(A,B)`
Complex transpose	`A'`	`ctranspose(A)`
Matrix transpose	`A.'`	`transpose(A)`

Examples

Here are two vectors, and the results of various matrix and array operations on them, printed with `format rat`.

Matrix Operations		**Array Operations**	

`x`	`1`
	`2`
	`3`
		`y`	`4`
			`5`
			`6`

`x'`	`1 2 3`	`y'`	`4 5 6`

`x+y`	`5`
	`7`
	`9`
		`x-y`	`-3`
			`-3`
			`-3`

Matrix Operations		Array Operations	
x + 2	3 4 5	x-2	-1 0 1
x * y	Error	x.*y	4 10 18
x'*y	32	x'.*y	Error
x*y'	4 5 6 8 10 12 12 15 18	x.*y'	Error
x*2	2 4 6	x.*2	2 4 6
x\y	16/7	x.\y	4 5/2 2
2\x	1/2 1 3/2	2./x	2 1 2/3
x/y	0 0 1/6 0 0 1/3 0 0 1/2	x./y	1/4 2/5 1/2
x/2	1/2 1 3/2	x./2	1/2 1 3/2
x^y	Error	x.^y	1 32 729
x^2	Error	x.^2	1 4 9

Matrix Operations		Array Operations	

`2^x`	`Error`	`2.^x`	`2`
			`4`
			`8`

`(x+i*y)'`	`1 - 4i   2 - 5i   3 - 6i`		
`(x+i*y).'`	`1 + 4i   2 + 5i   3 + 6i`		

Algorithm

The specific algorithm used for solving the simultaneous linear equations denoted by `X = A\B` and `X = B/A` depends upon the structure of the coefficient matrix `A`. To determine the structure of `A` and select the appropriate algorithm, MATLAB follows this precedence:

1. **If A is sparse, square, and banded**, then banded solvers are used. Band density is (# nonzeros in the band)/(# nonzeros in a full band). Band density = `1.0` if there are no zeros on any of the three diagonals.
   - If `A` is real and tridiagonal, i.e., band density = `1.0`, and `B` is real with only one column, `X` is computed quickly using Gaussian elimination without pivoting.
   - If the tridiagonal solver detects a need for pivoting, or if `A` or `B` is not real, or if `B` has more than one column, but `A` is banded with band density greater than the `spparms` parameter `'bandden'` (default = `0.5`), then `X` is computed using LAPACK.
2. **If A is an upper or lower triangular matrix**, then `X` is computed quickly with a backsubstitution algorithm for upper triangular matrices, or a forward substitution algorithm for lower triangular martrices. The check for triangularity is done for full matrices by testing for zero elements and for sparse matrices by accessing the sparse data structure.
3. **If A is a permutation of a triangular matrix**, then `X` is computed with a permuted backsubstitution algorithm.
4. **If A is symmetric, or Hermitian, and has positive diagonal elements**, then a Cholesky factorization is attempted (see `chol`). If `A` is found to be positive definite, the Cholesky factorization attempt is successful and requires less than half the time of a general factorization. Nonpositive definite matrices are usually detected almost immediately, so this check also requires little time. If successful, the Cholesky factorization is

```
A = R'*R
```

where R is upper triangular. The solution X is computed by solving two triangular systems,

```
X = R\(R'\B)
```

If A is sparse, a symmetric minimum degree preordering is applied (see symmmd and spparms). The algorithm is:

```
perm = symmmd(A);          % Symmetric minimum degree reordering
R = chol(A(perm,perm));    % Cholesky factorization
Y = R'\B(perm);            % Lower triangular solve
X(perm,:) = R\Y;           % Upper triangular solve
```

5 **If A is Hessenberg**, but not sparse, it is reduced to an upper triangular matrix and that system is solved via substitution.

6 **If A is square**, and does not satisfy criteria 1 through 5, then a general triangular factorization is computed by Gaussian elimination with partial pivoting (see lu). This results in

```
A = L*U
```

where L is a permutation of a lower triangular matrix and U is an upper triangular matrix. Then X is computed by solving two permuted triangular systems.

```
X = U\(L\B)
```

If A is sparse, then UMFPACK is used to compute X. The computations result in

```
P*A*Q = L*U
```

where P is a row permutaion matrix and Q is a column reordering matrix. Then X = Q*(U\L\(P*B)).

7 **If A is not square**, then Householder reflections are used to compute an orthogonal-triangular factorization.

```
A*P = Q*R
```

where P is a permutation, Q is orthogonal and R is upper triangular (see qr). The least squares solution X is computed with

```
X = P*(R\(Q'*B))
```

If `A` is sparse, then MATLAB computes a least squares solution using the sparse `qr` factorization of `A`.

Note For sparse matrices, to see information about choice of algorithm and storage allocation, set the `spparms` parameter `'spumoni' = 1`.

Note Backslash is not implemented for sparse matrices `A` that are complex but not square.

MATLAB uses LAPACK routines to compute these matrix factorizations:

Matrix	Real	Complex
Sparse square banded with band density > `'bandden'`.	`DGBTRF, DGBTRS`	`ZGBTRF, ZGBTRS`
Full square, symmetric (Hermitian) positive definite	`DLANGE`, `DPOTRF`, `DPOTRS`, `DPOCON`	`ZLANGE`, `ZPOTRF`, `ZPOTRS` `ZPOCON`
Full square, general case	`DLANGE`, `DGESV`, `DGECON`	`ZLANGE`, `ZGESV`, `ZGECON`
Full non-square	`DGEQP3`, `DORMQR`, `DTRTRS`	`ZGEQP3`, `ZORMQR`, `ZTRTRS`
For other cases (sparse, triangular and Hessenberg) MATLAB does not use LAPACK.		

Diagnostics

- From matrix division, if a square `A` is singular:

```
Warning: Matrix is singular to working precision.
```

- From element-wise division, if the divisor has zero elements:

```
Warning: Divide by zero.
```

Matrix division and element-wise division may produce `NaN`s or `Inf`s where appropriate.

- If the inverse was found, but is not reliable:

```
Warning: Matrix is close to singular or badly scaled.
    Results may be inaccurate.  RCOND = xxx
```

- From matrix division, if a nonsquare `A` is rank deficient:

```
Warning: Rank deficient, rank = xxx tol = xxx
```

See Also

`chol`, `det`, `inv`, `lu`, `orth`, `permute`, `ipermute`, `qr`, `rref`

References

[1] Anderson, E., Z. Bai, C. Bischof, S. Blackford, J. Demmel, J. Dongarra, J. Du Croz, A. Greenbaum, S. Hammarling, A. McKenney, and D. Sorensen, *LAPACK User's Guide* (`http://www.netlib.org/lapack/lug/lapack_lug.html`), Third Edition, SIAM, Philadelphia, 1999.

[2] Davis, T.A., *UMFPACK Version 4.0 User Guide* (`http://www.cise.ufl.edu/research/sparse/umfpack/v4.0/UserGuide.pdf`), Dept. of Computer and Information Science and Engineering, Univ. of Florida, Gainesville, FL, 2002.

Purpose Relational operations

Syntax

```
A < B
A > B
A <= B
A >= B
A == B
A ~= B
```

Description The relational operators are <, >, <=, >=, ==, and ~=. Relational operators perform element-by-element comparisons between two arrays. They return a `logical` array of the same size, with elements set to true (1) where the relation is true, and elements set to false (0) where it is not.

The operators <, >, <=, and >= use only the real part of their operands for the comparison. The operators == and ~= test real and imaginary parts.

To test if two strings are equivalent, use `strcmp`, which allows vectors of dissimilar length to be compared.

Examples If one of the operands is a scalar and the other a matrix, the scalar expands to the size of the matrix. For example, the two pairs of statements:

```
X = 5; X >= [1 2 3; 4 5 6; 7 8 10]
X = 5*ones(3,3); X >= [1 2 3; 4 5 6; 7 8 10]
```

produce the same result:

```
ans =

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

See Also `all`, `any`, `find`, `strcmp`

The logical operators `&`, `|`, `~`

Logical Operators, Element-wise & | ~

Purpose

Element-wise logical operations on arrays

Syntax

```
A & B
A | B
~A
```

Description

The symbols &, |, and ~ are the logical array operators AND, OR, and NOT. They work element-by-element on arrays, with 0 representing logical false (F), and anything nonzero representing logical true (T). The logical operators return a `logical` array with elements set to true (1) or false (0), as appropriate.

The & operator does a logical AND, the | operator does a logical OR, and ~A complements the elements of A. The function `xor(A,B)` implements the exclusive OR operation. The truth table for these operators and functions is shown below.

Inputs		**and**	**or**	**not**	**xor**
A	B	A & B	A | B	~A	xor(A,B)
0	0	0	0	1	0
0	1	0	1	1	1
1	0	0	1	0	1
1	1	1	1	0	0

The precedence for the logical operators with respect to each other is

Operator	**Operation**	**Priority**
~	NOT	Highest
&	Element-wise AND	
|	Element-wise OR	
&&	Short-circuit AND	
||	Short-circuit OR	Lowest

Remarks

MATLAB always gives the & operator precedence over the | operator. Although MATLAB typically evaluates expressions from left to right, the expression `a|b&c` is evaluated as `a|(b&c)`. It is a good idea to use parentheses to explicitly specify the intended precedence of statements containing combinations of & and |.

These logical operators have M-file function equivalents, as shown.

Logical Operation	Equivalent Function
`A & B`	and(A,B)
`A | B`	or(A,B)
`~A`	not(A)

Examples

This example shows the logical `OR` of the elements in the vector `u` with the corresponding elements in the vector `v`:

```
u = [0 0 1 1 0 1];
v = [0 1 1 0 0 1];
u | v

ans =
   0   1   1   1   0   1
```

See Also

`all`, `any`, `find`, `logical`, `xor`, `true`, `false`

Logical Operators, Short-circuit: &&, ||

Relational Operators: <, <=, >, >=, ==, ~=

Logical Operators, Short-circuit && ||

Purpose

Logical operations, with short-circuiting capability

Syntax

```
A && B
A || B
```

Description

The symbols `&&` and `||` are the logical `AND` and `OR` operators used to evaluate logical expressions. Use `&&` and `||` in the evaluation of compound expressions of the form

```
expression_1 && expression_2
```

where `expression_1` and `expression_2` each evaluate to a scalar, logical result.

The `&&` and `||` operators support short-circuiting. This means that the second operand is evaluated only when the result is not fully determined by the first operand. See "Short-circuit Operators" in the MATLAB documentation for a discussion on short-circuiting with `&&` and `||`.

Note Always use the `&&` and `||` operators when short-circuiting is required. Using the element-wise operators (`&` and `|`) for short-circuiting may yield unexpected results.

Examples

In the following statement, it doesn't make sense to evaluate the relation on the right if the divisor, `b`, is zero. The test on the left is put in to avoid generating a warning under these circumstances:

```
x = (b ~= 0) && (a/b > 18.5)
```

By definition, if any operands of an `AND` expression are `false`, the entire expression must be `false`. So, if `(b ~= 0)` evaluates to `false`, MATLAB assumes the entire expression to be `false` and terminates its evaluation of the expression early. This avoids the warning that would be generated if MATLAB were to evaluate the operand on the right.

See Also

`all`, `any`, `find`, `logical`, `xor`, `true`, `false`

Logical operators, Element-wise: `&`, `|`, `~`

Relational Operators: <, <=, >, >=, ==, ~=

Special Characters [ ] ( ) {} = ' . ... , ; % !

Purpose Special characters

Syntax `[ ] ( ) {} = ' . ... , ; % !`

Description

`[ ]` Brackets are used to form vectors and matrices. `[6.9 9.64 sqrt(-1)]` is a vector with three elements separated by blanks. `[6.9, 9.64, i]` is the same thing. `[1+j 2-j 3]` and `[1 +j 2 -j 3]` are not the same. The first has three elements, the second has five.

`[11 12 13; 21 22 23]` is a 2-by-3 matrix. The semicolon ends the first row.

Vectors and matrices can be used inside `[ ]` brackets. `[A B;C]` is allowed if the number of rows of `A` equals the number of rows of `B` and the number of columns of `A` plus the number of columns of `B` equals the number of columns of `C`. This rule generalizes in a hopefully obvious way to allow fairly complicated constructions.

`A = [ ]` stores an empty matrix in `A`. `A(m,:) = [ ]` deletes row `m` of `A`. `A(:,n) = [ ]` deletes column `n` of `A`. `A(n) = [ ]` reshapes `A` into a column vector and deletes the third element.

`[A1,A2,A3...] = function` assigns function output to multiple variables.

For the use of `[` and `]` on the left of an "=" in multiple assignment statements, see `lu`, `eig`, `svd`, and so on.

`{ }` Curly braces are used in cell array assignment statements. For example,

`A(2,1) = {[1 2 3; 4 5 6]}`, or `A{2,2} = ('str')`. See `help paren` for more information about `{ }`.

`( )` Parentheses are used to indicate precedence in arithmetic expressions in the usual way. They are used to enclose arguments of functions in the usual way. They are also used to enclose subscripts of vectors and matrices in a manner somewhat more general than usual. If `X` and `V` are vectors, then `X(V)` is `[X(V(1)), X(V(2)), ..., X(V(n))]`. The components of `V` must be integers to be used as subscripts. An error occurs if any such subscript is less than 1 or greater than the size of `X`. Some examples are

- `X(3)` is the third element of `X`.
- `X([1 2 3])` is the first three elements of `X`.

See `help paren` for more information about `( )`.

If `X` has `n` components, `X(n:–1:1)` reverses them. The same indirect subscripting works in matrices. If `V` has `m` components and `W` has `n` components, then `A(V,W)` is the m-by-n matrix formed from the elements of `A` whose subscripts are the elements of `V` and `W`. For example, `A([1,5],:) = A([5,1],:)` interchanges rows 1 and 5 of `A`.

`=` Used in assignment statements. `B = A` stores the elements of `A` in `B`. == is the relational equals operator. See the Relational Operators page.

`'` Matrix transpose. `X'` is the complex conjugate transpose of `X`. `X.'` is the nonconjugate transpose.

Quotation mark. `'any text'` is a vector whose components are the ASCII codes for the characters. A quotation mark within the text is indicated by two quotation marks.

`.` Decimal point. `314/100`, `3.14` and `.314e1` are all the same. Element-by-element operations. These are obtained using `.*` , `.^` , `./`, or `.\`. See the Arithmetic Operators page.

`.` Field access. `A.(field)` and `A(i).field`, when `A` is a structure, access the contents of `field`.

`..` Parent directory. See `cd`.

`...` Continuation. Three or more points at the end of a line indicate continuation.

,	Comma. Used to separate matrix subscripts and function arguments. Used to separate statements in multistatement lines. For multi-statement lines, the comma can be replaced by a semicolon to suppress printing.
;	Semicolon. Used inside brackets to end rows. Used after an expression or statement to suppress printing or to separate statements.
%	Percent. The percent symbol denotes a comment; it indicates a logical end of line. Any following text is ignored. MATLAB displays the first contiguous comment lines in a M-file in response to a `help` command.
!	Exclamation point. Indicates that the rest of the input line is issued as a command to the operating system. On the PC, adding `&` to the end of the `!` command line, as in `!dir &`, causes the output to appear in a separate window.

Remarks

Some uses of special characters have M-file function equivalents, as shown:

Horizontal concatenation	`[A,B,C...]`	`horzcat(A,B,C...)`
Vertical concatenation	`[A;B;C...]`	`vertcat(A,B,C...)`
Subscript reference	`A(i,j,k...)`	`subsref(A,S)`. See `help subsref`.
Subscript assignment	`A(i,j,k...)= B`	`subsasgn(A,S,B)`. See `help subsasgn`.

See Also

The arithmetic operators +, –, *, /, `\`, ^, '

The relational operators <, <=, >, >=, ==, ~=

The logical operators &, `|`, ~

Purpose Create vectors, array subscripting, and `for` loop iterations

Description The colon is one of the most useful operators in MATLAB. It can create vectors, subscript arrays, and specify `for` iterations.

The colon operator uses the following rules to create regularly spaced vectors:

`j:k`	is the same as `[j,j+1,...,k]`
`j:k`	is empty if `j > k`
`j:i:k`	is the same as `[j,j+i,j+2i, ...,k]`
`j:i:k`	is empty if `i > 0` and `j > k` or if `i < 0` and `j < k`

where `i`,`j`, and `k` are all scalars.

Below are the definitions that govern the use of the colon to pick out selected rows, columns, and elements of vectors, matrices, and higher-dimensional arrays:

`A(:,j)`	is the `j`-th column of `A`
`A(i,:)`	is the `i`-th row of `A`
`A(:,:)`	is the equivalent two-dimensional array. For matrices this is the same as `A`.
`A(j:k)`	is `A(j), A(j+1),...,A(k)`
`A(:,j:k)`	is `A(:,j), A(:,j+1),...,A(:,k)`
`A(:,:,k)`	is the `k`th page of three-dimensional array `A`.
`A(i,j,k,:)`	is a vector in four-dimensional array `A`. The vector includes `A(i,j,k,1)`, `A(i,j,k,2)`, `A(i,j,k,3)`, and so on.
`A(:)`	is all the elements of `A`, regarded as a single column. On the left side of an assignment statement, `A(:)` fills `A`, preserving its shape from before. In this case, the right side must contain the same number of elements as `A`.

Examples

Using the colon with integers,

```
D = 1:4
```

results in

```
D =
     1     2     3     4
```

Using two colons to create a vector with arbitrary real increments between the elements,

```
E = 0:.1:.5
```

results in

```
E =
     0    0.1000    0.2000    0.3000    0.4000    0.5000
```

The command

```
A(:,:,2) = pascal(3)
```

generates a three-dimensional array whose first page is all zeros.

```
A(:,:,1) =
      0     0     0
      0     0     0
      0     0     0

A(:,:,2) =
      1     1     1
      1     2     3
      1     3     6
```

See Also

`for`, `linspace`, `logspace`, `reshape`

abs

Purpose

Absolute value and complex magnitude

Syntax

```
Y = abs(X)
```

Description

`abs(X)` returns an array `Y` such that each element of `Y` is the absolute value of the corresponding element of `X`.

If `X` is complex, `abs(X)` returns the complex modulus (magnitude), which is the same as

```
sqrt(real(X).^2 + imag(X).^2)
```

Examples

```
abs(-5)

ans =
     5

abs(3+4i)

ans =
     5
```

See Also

`angle`, `sign`, `unwrap`

Purpose

Inverse cosine

Syntax

```
Y = acos(X)
```

Description

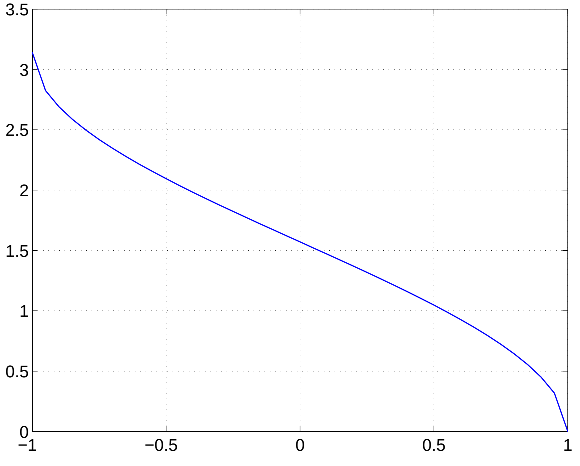
`Y = acos(X)` returns the inverse cosine (arccosine) for each element of `X`. For real elements of `X` in the domain $[-1, 1]$, `acos(X)` is real and in the range $[0, \pi]$. For real elements of `X` outside the domain $[-1, 1]$, `acos(X)` is complex.

The `acos` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples

Graph the inverse cosine function over the domain $-1 \le x \le 1$.

```
x = -1:.05:1;
plot(x,acos(x)), grid on
```



Definition

The inverse cosine can be defined as

$$\cos^{-1}(z) = -i\log\left[z + i(1-z^2)^{\frac{1}{2}}\right]$$

Algorithm acos uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also acosh, cos

acosh

Purpose Inverse hyperbolic cosine

Syntax

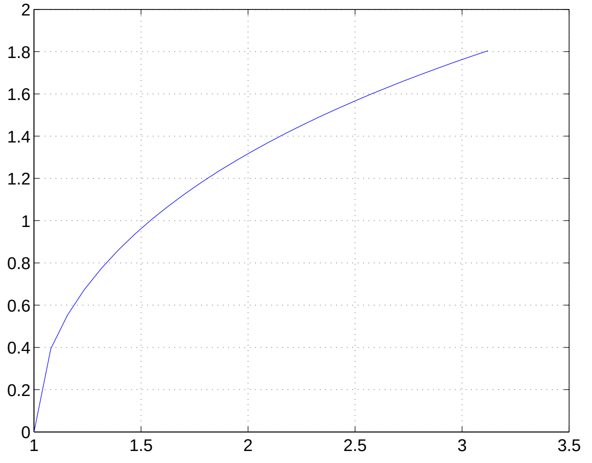
```
Y = acosh(X)
```

Description `Y = acosh(X)` returns the inverse hyperbolic cosine for each element of `X`.

The `acosh` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples Graph the inverse hyperbolic cosine function over the domain $1 \le x \le \pi$.

```
x = 1:pi/40:pi;
plot(x,acosh(x)), grid on
```



Definition The hyperbolic inverse cosine can be defined as

$$\cosh^{-1}(z) = \log\left[z + (z^2 - 1)^{\frac{1}{2}}\right]$$

Algorithm `acosh` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also acos, cosh

Purpose Inverse cotangent

Syntax

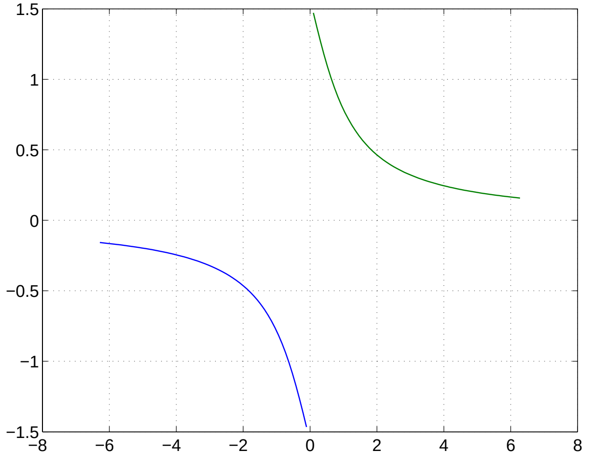
```
Y = acot(X)
```

Description `Y = acot(X)` returns the inverse cotangent (arccotangent) for each element of `X`.

The `acot` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples Graph the inverse cotangent over the domains $-2\pi \le x < 0$ and $0 < x \le 2\pi$.

```
x1 = -2*pi:pi/30:-0.1;
x2 = 0.1:pi/30:2*pi;
plot(x1,acot(x1),x2,acot(x2)), grid on
```



Definition The inverse cotangent can be defined as

$$\cot^{-1}(z) = \tan^{-1}\left(\frac{1}{z}\right)$$

Algorithm `acot` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also `cot`, `acoth`

acoth

Purpose

Inverse hyperbolic cotangent

Syntax

```
Y = acoth(X)
```

Description

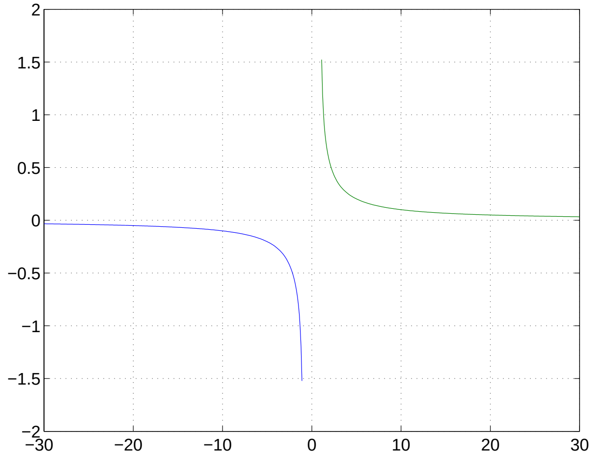
`Y = acoth(X)` returns the inverse hyperbolic cotangent for each element of `X`.

The `acoth` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples

Graph the inverse hyperbolic cotangent over the domains $-30 \le x < -1$ and $1 < x \le 30$.

```
x1 = -30:0.1:-1.1;
x2 = 1.1:0.1:30;
plot(x1,acoth(x1),x2,acoth(x2)), grid on
```



Definition

The hyperbolic inverse cotangent can be defined as

$$\coth^{-1}(z) = \tanh^{-1}\left(\frac{1}{z}\right)$$

Algorithm

acoth uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see http://www.netlib.org.

See Also

acot, coth

Purpose Inverse cosecant

Syntax

```
Y = acsc(X)
```

Description

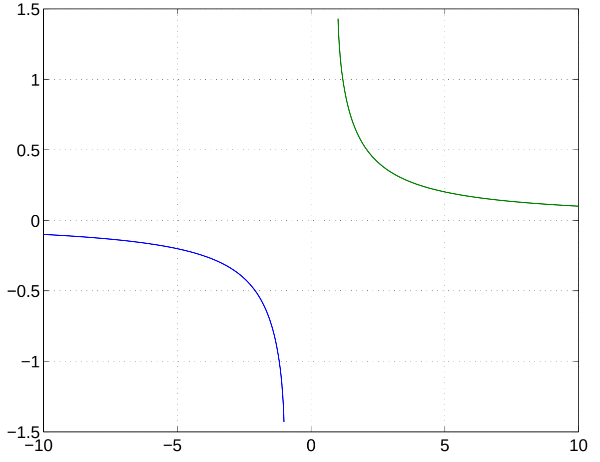
`Y = acsc(X)` returns the inverse cosecant (arccosecant) for each element of `X`.

The `acsc` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples

Graph the inverse cosecant over the domains $-10 \le x < -1$ and $1 < x \le 10$.

```
x1 = -10:0.01:-1.01;
x2 = 1.01:0.01:10;
plot(x1,acsc(x1),x2,acsc(x2)), grid on
```



Definition

The inverse cosecant can be defined as

$$\csc^{-1}(z) = \sin^{-1}\left(\frac{1}{z}\right)$$

Algorithm

`acsc` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also csc, acsch

Purpose Inverse cosecant and inverse hyperbolic cosecant

Syntax

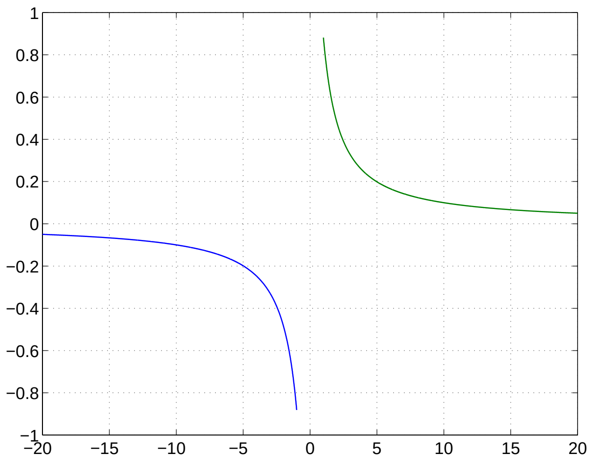
```
Y = acsch(X)
```

Description `Y = acsch(X)` returns the inverse hyperbolic cosecant for each element of `X`.

The `acsch` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples Graph the inverse hyperbolic cosecant over the domains $-20 \le x \le -1$ and $1 \le x \le 20$.

```
x1 = -20:0.01:-1;
x2 = 1:0.01:20;
plot(x1,acsch(x1),x2,acsch(x2)), grid on
```



Definition The hyperbolic inverse cosecant can be defined as

$$\operatorname{csch}^{-1}(z) = \sinh^{-1}\left(\frac{1}{z}\right)$$

Algorithm

acsc uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see http://www.netlib.org.

See Also

acsc, csch

actxcontrol

Purpose Create a COM control in a figure window

Syntax

```
h = actxcontrol (progid [, position [, fig_handle ...
   [, callback | {event1 eventhandler1; event2 eventhandler2; ...}
   [, filename]]]])
```

Arguments

`progid`
String that is the name of the control to create. The control vendor provides this string.

`position`
Position vector containing the `x` and `y` location and the `xsize` and `ysize` of the control, expressed in pixel units as `[x y xsize ysize]`. Defaults to `[20 20 60 60]`.

`fig_handle`
Handle Graphics handle of the figure window in which the control is to be created. If the control should be invisible, use the handle of an invisible figure window. Defaults to `gcf`.

`callback`
Name of an M-function that accepts a variable number of arguments. This function will be called whenever the control triggers an event. Each argument is converted to a MATLAB string. See the section, "Writing Event Handlers" in the External Interfaces documentation for more information on handling control events.

`event`
Triggered event specified by either number or name.

`eventhandler`
Name of an M-function that accepts a variable number of arguments. This function will be called whenever the control triggers the event associated with it. See "Writing Event Handlers" in the External Interfaces documentation for more information on handling control events.

`filename`
The name of a file to which a previously created control has been saved. When you specify `filename`, MATLAB creates a new control using the `position`, `handle`, and `event/eventhandler` arguments, and then initializes the control from the specified file. The `progid` argument in `actxcontrol` must match the `progid` of the saved control.

Description

Create a COM control at a particular location within a figure window. If the parent figure window is invisible, the control will be invisible. The returned COM object represents the default interface for the control. This interface must be released through a call to `release` when it is no longer needed to free the memory and resources used by the interface. Note that releasing the interface does not delete the control itself (use the `delete` command to delete the control.)

The strings specified in the `callback`, `event`, and `eventhandler` arguments are not case sensitive.

Note There are two ways to handle events. You can create a single handler (`callback`) for all events, or you can specify a cell array that contains pairs of events and event handlers. In the cell array format, specify events by name in a quoted string. There is no limit to the number of pairs that can be specified in the cell array. Although using the single callback method may be easier in some cases, using the cell array technique creates more efficient code that results in better performance.

For an example callback event handler, see the file `sampev.m` in the `toolbox\matlab\winfun\comcli` directory.

Examples

Basic Control Methods

Create a control that runs Microsoft's Calendar application:

```
f = figure('pos',[300 300 500 500]);
cal = actxcontrol('mscal.calendar', [0 0 500 500], f)
cal =
    COM.mscal.calendar
```

Call the `get` method on `cal` to list all properties of the Calendar:

```
get(cal)
             BackColor: 2.1475e+009
                   Day: 23
               DayFont: [1x1 Interface.mscal.calendar.DayFont]
                 Value: '8/20/2001'
                   .
```

.

Read just one property to record today's date:

```
date = get(cal, 'Value')
date =
   8/23/2001
```

Set the Day property to a new value:

```
set(cal, 'Day', 5);
date = get(cal, 'Value')
date =
   8/5/2001
```

Calling invoke with no arguments lists all available methods:

```
meth = invoke(cal)
meth =
          NextDay: 'HRESULT NextDay(handle)'
        NextMonth: 'HRESULT NextMonth(handle)'
         NextWeek: 'HRESULT NextWeek(handle)'
         NextYear: 'HRESULT NextYear(handle)'
            .
            .
```

Invoke the NextWeek method to advance the current date by one week:

```
NextWeek(cal);
date = get(cal, 'Value')
date =
   8/12/2001
```

Call events to list all Calendar events that can be triggered:

```
events(cal)
ans =
   Click = void Click()
   DblClick = void DblClick()
   KeyDown = void KeyDown(int16 KeyCode, int16 Shift)
   KeyPress = void KeyPress(int16 KeyAscii)
   KeyUp = void KeyUp(int16 KeyCode, int16 Shift)
   BeforeUpdate = void BeforeUpdate(int16 Cancel)
   AfterUpdate = void AfterUpdate()
```

```
NewMonth = void NewMonth()
NewYear = void NewYear()
```

Set Up Event Handling

See the section, Sample Event Handlers in the External Interfaces documentation for examples of event handler functions and how to register them with MATLAB.

See Also

`actxserver`, `release`, `delete`, `save`, `load`

actxserver

Purpose

Create a COM Automation server and return a COM object for the server's default interface

Syntax

```
h = actxserver (progid [, machinename])
```

Arguments

`progid`
This is a string that is the name of the control to instantiate. This string is provided by the control or server vendor and should be obtained from the vendor's documentation. For example, the `progid` for MATLAB is `matlab.application`.

`machinename`
This is the name of a remote machine on which the server is to be run. This argument is optional and is used only in environments that support Distributed Component Object Model (DCOM) — see "Using MATLAB As a DCOM Server Client" in the External Interfaces documentation. This can be an IP address or a DNS name.

Description

Create a COM Automation server and return a COM object that represents the server's default interface. Local/Remote servers differ from controls in that they are run in a separate address space (and possibly on a separate machine) and are not part of the MATLAB process. Additionally, any user interface that they display will be in a separate window and will not be attached to the MATLAB process. Examples of local servers are Microsoft Excel and Microsoft Word. There is currently no support for events generated from automation servers.

Examples

Launch Microsoft Excel and make the main frame window visible:

```
e = actxserver ('Excel.Application')
e =
    COM.excel.application
set(e, 'Visible', 1);
```

Call the get method on the excel object to list all properties of the application:

```
get(e)
ans =
      Application: [1x1 Interface.excel.application.Application]
            Creator: 'xlCreatorCode'
             Parent: [1x1 Interface.Excel.Application.Parent]
          Workbooks: [1x1 Interface.excel.application.Workbooks]
       UsableHeight: 666.7500
                  .
                  .
```

Create an interface:

```
eWorkbooks = get(e, 'Workbooks')
eWorkbooks =
    Interface.excel.application.Workbooks
```

List all methods for that interface by calling invoke with just the handle argument:

```
invoke(eWorkbooks)
ans =
         Add: 'handle Add(handle, [Optional]Variant)'
       Close: 'void Close(handle)'
        Item: 'handle Item(handle, Variant)'
        Open: 'handle Open(handle, string, [Optional]Variant)'
    OpenText: 'void OpenText(handle, string, [Optional]Variant)'
```

Invoke the Add method on workbooks to add a new workbook, also creating a new interface:

```
w = Add(eWorkbooks)
w =
    Interface.Excel.Application.Workbooks.Add
```

Quit the application and delete the object:

```
Quit(e);
delete(e);
```

See Also actxcontrol, release, delete, save, load

Purpose Add a frame to an Audio Video Interleaved (AVI) file.

Syntax

```
aviobj = addframe(aviobj,frame)
aviobj = addframe(aviobj,frame1,frame2,frame3,...)
aviobj = addframe(aviobj,mov)
aviobj = addframe(aviobj,h)
```

Description

`aviobj = addframe(aviobj,frame)` appends the data in `frame` to the AVI file identified by `aviobj`, which was created by a previous call to `avifile`. `frame` can be either an indexed image (m-by-n) or a truecolor image (m-by-n-by-3) of `double` or `uint8` precision. If `frame` is not the first frame added to the AVI file, it must be consistent with the dimensions of the previous frames.

`addframe` returns a handle to the updated `AVI` file object, `aviobj`. For example, addframe updates the `TotalFrames` property of the AVI file object each time it adds a frame to the AVI file.

`aviobj = addframe(aviobj,frame1,frame2,frame3,...)` adds multiple frames to an AVI file.

`aviobj = addframe(aviobj,mov)` appends the frame(s) contained in the MATLAB movie, `mov`, to the AVI file, `aviobj`. MATLAB movies that store frames as indexed images use the colormap in the first frame as the colormap for the AVI file, unless the colormap has been previously set.

`aviobj = addframe(aviobj,h)` captures a frame from the figure or axis handle `h`, and appends this frame to the AVI file. `addframe` renders the figure into an offscreen array before appending it to the AVI file. This ensures that the figure is written correctly to the AVI file even if the figure is obscured on the screen by another window or screen saver.

Note If an animation uses XOR graphics, you must use `getframe` to capture the graphics into a frame of a MATLAB movie. You can then add the frame to an AVI movie using the `addframe` syntax, `aviobj = addframe(aviobj,mov)`. See the example for an illustration.

Example This example calls `addframe` to add frames to the AVI file object, `aviobj`.

```
fig=figure;
set(fig,'DoubleBuffer','on');
set(gca,'xlim',[-80 80],'ylim',[-80 80],...
   'nextplot','replace','Visible','off')

aviobj = avifile('example.avi')

x = -pi:.1:pi;
radius = 0:length(x);
for i=1:length(x)
   h = patch(sin(x)*radius(i),cos(x)*radius(i),...
             [abs(cos(x(i))) 0 0]);
   set(h,'EraseMode','xor');
   frame = getframe(gca);
   aviobj = addframe(aviobj,frame);
end

aviobj = close(aviobj);
```

See Also avifile, close, movie2avi

Purpose Add directories to MATLAB search path

Graphical Interface As an alternative to the addpath function, use the **Set Path** dialog box. To open it, select **Set Path** from the **File** menu in the MATLAB desktop.

Syntax

```
addpath('directory')
addpath('dir','dir2','dir3' ...)
addpath('dir','dir2','dir3' ...'-flag')
addpath dir1 dir2 dir3 ... -flag
```

Description

`addpath('directory')` prepends the specified directory to the current MATLAB search path, that is, it adds them to the top of the path. Use the full pathname for `directory`.

`addpath('dir','dir2','dir3' ...)` prepends all the specified directories to the path. Use the full pathname for each `dir`.

`addpath('dir','dir2','dir3' ...'-flag')` either prepends or appends the specified directories to the path depending on the value of `flag`.

flag Argument	Result
`0` or `begin`	Prepend specified directories
`1` or `end`	Append specified directories (add to bottom/end)

`addpath dir1 dir2 dir3 ... -flag` is the unquoted form of the syntax.

Examples

For the current path, viewed by typing `path`,

```
MATLABPATH
c:\matlab\toolbox\general
c:\matlab\toolbox\ops
c:\matlab\toolbox\strfun
```

you can add `c:/matlab/mymfiles` to the front of the path by typing

```
addpath('c:/matlab/mymfiles')
```

Verify that the files were added to the path by typing

```
path
```

and MATLAB returns

```
MATLABPATH
c:\matlab\mymfiles
c:\matlab\toolbox\general
c:\matlab\toolbox\ops
c:\matlab\toolbox\strfun
```

See Also

`path`, `pathtool`, `genpath`, `rehash`, `rmpath`

addproperty (COM)

Purpose

Add custom property to COM object

Syntax

```
addproperty(h, 'propertyname')
```

Arguments

`h`
Handle for a COM object previously returned from `actxcontrol`, `actxserver`, `get`, or `invoke`.

`propertyname`
A string specifying the name of the custom property to add to the object or interface.

Description

Add a custom property, `propertyname`, to the object or interface, `h`. You can assign a value to that property using `set`.

Examples

Create an `mwsamp` control and add a new property named `Position` to it. Assign an array value to the property:

```
f = figure('pos', [100 200 200 200]);
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 200 200], f);
get(h)
     Label: 'Label'
    Radius: 20

addproperty(h, 'Position');
set(h, 'Position', [200 120]);
get(h)
       Label: 'Label'
      Radius: 20
    Position: [200 120]

get(h, 'Position')
ans =
   200   120
```

See Also

`deleteproperty`, `get`, `set`, `inspect`

Purpose

Airy functions

Syntax

```
W = airy(Z)
W = airy(k,Z)
[W,ierr] = airy(k,Z)
```

Definition

The Airy functions form a pair of linearly independent solutions to

$$\frac{d^2W}{dZ^2} - ZW = 0$$

The relationship between the Airy and modified Bessel functions is

$$Ai(Z) = \left[\frac{1}{\pi}\sqrt{Z/3}\right] K_{1/3}(\zeta)$$

$$Bi(Z) = \sqrt{Z/3}\ [I_{-1/3}(\zeta) + I_{1/3}(\zeta)]$$

where

$$\zeta = \frac{2}{3}Z^{3/2}$$

Description

`W = airy(Z)` returns the Airy function, $Ai(Z)$, for each element of the complex array `Z`.

`W = airy(k,Z)` returns different results depending on the value of `k`.

k	Returns
`0`	The same result as `airy(Z)`
`1`	The derivative, $Ai'(Z)$
`2`	The Airy function of the second kind, $Bi(Z)$
`3`	The derivative, $Bi'(Z)$

`[W,ierr] = airy(k,Z)` also returns completion flags in an array the same size as `W`.

ierr	Description
0	`airy` succesfully computed the Airy function for this element.
1	Illegal arguments
2	Overflow. Returns `Inf`
3	Some loss of accuracy in argument reduction
4	Unacceptable loss of accuracy, `Z` too large
5	No convergence. Returns `NaN`

See Also

`besseli`, `besselj`, `besselk`, `bessely`

References

[1] Amos, D. E., "A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[2] Amos, D. E., "A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Trans. Math. Software*, 1986.

Purpose Set or query the axes alpha limits

Syntax

```
alpha_limits = alim
alim([amin amax])
alim_mode = alim('mode')
alim('alim_mode')
alim(axes_handle,...)
```

Description

`alpha_limits = alim` returns the alpha limits (the axes `ALim` property) of the current axes.

`alim([amin amax])` sets the alpha limits to the specified values. `amin` is the value of the data mapped to the first alpha value in the alphamap, and `amax` is the value of the data mapped to the last alpha value in the alphamap. Data values in between are linearly interpolated across the alphamap, while data values outside are clamped to either the first or last alphamap value, whichever is closest.

`alim_mode = alim('mode')` returns the alpha limits mode (the axes `ALimMode` property) of the current axes.

`alim('alim_mode')` sets the alpha limits mode on the current axes. `alim_mode` can be:

- auto – MATLAB automatically sets the alpha limits based on the alpha data of the objects in the axes.
- `manual` – MATLAB does not change the alpha limits.

`alim(axes_handle,...)` operates on the specified axes.

See Also

`alpha`, `alphamap`, `caxis`

Axes `ALim` and `ALimMode` properties

Patch `FaceVertexAlphaData` property

Image and surface `AlphaData` properties

Transparency for related functions

Transparency in 3-D Visualization for examples

Purpose Test to determine if all elements are nonzero

Syntax

```
B = all(A)
B = all(A,dim)
```

Description

`B = all(A)` tests whether *all* the elements along various dimensions of an array are nonzero or logical true (`1`).

If `A` is a vector, `all(A)` returns logical true (`1`) if all of the elements are nonzero, and returns logical false (`0`) if one or more elements are zero.

If `A` is a matrix, `all(A)` treats the columns of `A` as vectors, returning a row vector of `1`s and `0`s.

If `A` is a multidimensional array, `all(A)` treats the values along the first non-singleton dimension as vectors, returning a logical condition for each vector.

`B = all(A,`*`dim`*`)` tests along the dimension of `A` specified by scalar *`dim`*.

$$\begin{array}{|c|c|c|}\hline 1 & 1 & 1 \\ \hline 1 & 1 & 0 \\ \hline\end{array} \qquad \begin{array}{|c|c|c|}\hline 1 & 1 & 0 \\ \hline\end{array} \qquad \begin{array}{|c|}\hline 1 \\ \hline 0 \\ \hline\end{array}$$

A   all(A,1)   all(A,2)

Examples

Given,

```
A = [0.53 0.67 0.01 0.38 0.07 0.42 0.69]
```

then `B = (A < 0.5)` returns logical true (`1`) only where `A` is less than one half:

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

The `all` function reduces such a vector of logical conditions to a single condition. In this case, `all(B)` yields `0`.

This makes `all` particularly useful in `if` statements,

```
if all(A < 0.5)
    do something
end
```

where code is executed depending on a single condition, not a vector of possibly conflicting conditions.

Applying the `all` function twice to a matrix, as in `all(all(A))`, always reduces it to a scalar condition.

```
all(all(eye(3)))
ans =
   0
```

See Also

`any`, logical operators, relational operators, `colon`

Other functions that collapse an array's dimensions include:

`max`, `mean`, `median`, `min`, `prod`, `std`, `sum`, `trapz`

allchild

Purpose Find all children of specified objects

Syntax

```
child_handles = allchild(handle_list)
```

Description

`child_handles = allchild(handle_list)` returns the list of all children (including ones with hidden handles) for each handle. If `handle_list` is a single element, allchild returns the output in a vector. Otherwise, the output is a cell array.

Examples

Compare the results returned by these two statements.

```
get(gca,'Children')
allchild(gca)
```

See Also

`findall`, `findobj`

Purpose

Set transparency properties for objects in current axes

Syntax

```
alpha(face_alpha)
alpha(alpha_data)
alpha(alpha_data_mapping)
alpha(object_handle,...)
```

Description

`alpha` sets one of three transparency properties, depending on what arguments you specify with the call to this function.

FaceAlpha

`alpha(face_alpha)` set the `FaceAlpha` property of all image, patch, and surface objects in the current axes. You can set `face_alpha` to:

- a scalar – set the `FaceAlpha` property to the specified value (for images, set the `AlphaData` property to the specified value)
- `'flat'` – set the `FaceAlpha` property to `flat`
- `'interp'` – set the `FaceAlpha` property to `interp`
- `'texture'` – set the `FaceAlpha` property to `texture`
- `'opaque'` – set the `FaceAlpha` property to `1`
- `'clear'` – set the `FaceAlpha` property to `0`

See Specifying a Single Transparency Value for more information.

AlphaData (Surface Objects)

`alpha(alpha_data)` sets the `AlphaData` property of all surface objects in the current axes. You can set `alpha_data` to:

- a matrix the same size as `CData` – sets the `AlphaData` property to the specified values
- `'x'` – set the `AlphaData` property to be the same as `XData`
- `'y'` – set the `AlphaData` property to be the same as `YData`
- `'z'` – set the `AlphaData` property to be the same as `ZData`
- `'color'` – set the `AlphaData` property to be the same as `CData`

- 'rand' – set the AlphaData property to a matrix of random values equal in size to CData

AlphaData (Image Objects)

alpha(alpha_data) sets the AlphaData property of all image objects in the current axes. You can set alpha_data to:

- a matrix the same size as CData – sets the AlphaData property to the specified value
- 'x' – ignored
- 'y' – ignored
- 'z' – ignored
- 'color' – set the AlphaData property to be the same as CData
- 'rand' – set the AlphaData property to a matrix of random values equal in size to CData

FaceVertexAlphaData (Patch Objects)

alpha(alpha_data) sets the FaceVertexAlphaData property of all patch objects in the current axes. You can set alpha_data to:

- a matrix the same size as FaceVertexCData – sets the FaceVertexAlphaData property to the specified value
- 'x' – set the FaceVertexAlphaData property to be the same as Vertices(:,1)
- 'y' – set the FaceVertexAlphaData property to be the same as Vertices(:,2)
- 'z' – set the FaceVertexAlphaData property to be the same as Vertices(:,3)
- 'color' – set the FaceVertexAlphaData property to be the same as FaceVertexCData
- 'rand' – set the FaceVertexAlphaData property to random values

See Mapping Data to Transparency for more information.

AlphaDataMapping

`alpha(alpha_data_mapping)` sets the `AlphaDataMapping` property of all image, patch, and surface objects in the current axes. You can set `alpha_data_mapping` to:

- `'scaled'` – set the `AlphaDataMapping` property to `scaled`
- `'direct'` – set the `AlphaDataMapping` property to `direct`
- `'none'` – set the `AlphaDataMapping` property to `none`

`alpha(object_handle,value)` set the transparency property only on the object identified by `object_handle`

See Also

`alim`, `alphamap`

Image: `AlphaData`, `AlphaDataMapping`

Patch: `FaceAlpha`, `FaceVertexAlphaData`, `AlphaDataMapping`

Surface: `FaceAlpha`, `AlphaData`, `AlphaDataMapping`

Transparency for related functions

Transparency in 3-D Visualization for examples

alphamap

Purpose

Specify the figure alphamap (transparency)

Syntax

```
alphamap(alpha_map)
alphamap('parameter')
alphamap('parameter',length)
alphamap('parameter',delta)
alphamap(figure_handle,...)
alpha_map = alphamap
alpha_map = alphamap(figure_handle)
alpha_map = alphamap('parameter')
```

Description

`alphamap` enables you to set or modify a figure's `Alphamap` property. Unless you specify a figure handle as the first argument, `alphamap` operates on the current figure.

`alphamap(alpha_map)` set the `AlphaMap` of the current figure to the specified m-by-1 array of alpha values.

`alphamap('parameter')` create a new or modify the current alphamap. You can specify the following parameters:

- `default` – set the `AlphaMap` property to the figure's default alphamap
- `rampup` – create a linear alphamap with increasing opacity (default `length` equals the current alphamap length)
- `rampdown` – create a linear alphamap with decreasing opacity (default `length` equals the current alphamap length)
- `vup` – create an alphamap that is opaque in the center and becomes more transparent linearly towards the beginning and end (default `length` equals the current alphamap length)
- `vdown` – create an alphamap that is transparent in the center and becomes more opaque linearly towards the beginning and end (default `length` equals the current alphamap length)
- `increase` – modify the alphamap making it more opaque (default `delta` is `.1`, which is added to the current values)
- `decrease` – modify the alphamap making it more transparent (default `delta` is `.1`, which is subtracted from the current values)

- `spin` – rotate the current alphamap (default `delta` is 1; note that delta must be an integer)

`alphamap('parameter',length)` creates a new alphamap with the length specified by `length` (used with parameters: `rampup`, `rampdown`, `vup`, `vdown`)

`alphamap('parameter',delta)` modifies the existing alphamap using the value specified by `delta` (used with parameters: `increase`, `decrease`, `spin`).

`alphamap(figure_handle,...)` performs the operation on the alphamap of the figure identified by `figure_handle`.

`alpha_map = alphamap` return the current alphamap.

`alpha_map = alphamap(figure_handle)` returns the current alphamap from the figure identified by `figure_handle`.

`alpha_map = alphamap('parameter')` retruns the alphamap modified by the `parameter`, but does not set the `AlphaMap` property.

See Also

`alim`, `alpha`

Image: `AlphaData`, `AlphaDataMapping`

Patch: `FaceAlpha`, `AlphaData`, `AlphaDataMapping`

Surface: `FaceAlpha`, `AlphaData`, `AlphaDataMapping`

Transparency for related functions

Transparency in 3-D Visualization for examples

angle

Purpose Phase angle

Syntax

```
P = angle(Z)
```

Description `P = angle(Z)` returns the phase angles, in radians, for each element of complex array `Z`. The angles lie between $\pm\pi$.

For complex `Z`, the magnitude `R` and phase angle `theta` are given by

```
R = abs(Z)
theta = angle(Z)
```

and the statement

```
Z = R.*exp(i*theta)
```

converts back to the original complex `Z`.

Examples

```
Z = [ 1 - 1i   2 + 1i   3 - 1i   4 + 1i
      1 + 2i   2 - 2i   3 + 2i   4 - 2i
      1 - 3i   2 + 3i   3 - 3i   4 + 3i
      1 + 4i   2 - 4i   3 + 4i   4 - 4i ]

P = angle(Z)

P =
   -0.7854    0.4636   -0.3218    0.2450
    1.1071   -0.7854    0.5880   -0.4636
   -1.2490    0.9828   -0.7854    0.6435
    1.3258   -1.1071    0.9273   -0.7854
```

Algorithm The `angle` function can be expressed as `angle(z) = imag(log(z)) = atan2(imag(z),real(z))`.

See Also `abs`, `atan2`, `unwrap`

Purpose The most recent answer

Syntax

```
ans
```

Description MATLAB creates the ans variable automatically when you specify no output argument.

Examples The statement

```
2+2
```

is the same as

```
ans = 2+2
```

See Also display

any

Purpose

Test for any nonzeros

Syntax

```
B = any(A)
B = any(A,dim)
```

Description

`B = any(A)` tests whether *any* of the elements along various dimensions of an array are nonzero or logical true (`1`).

If `A` is a vector, `any(A)` returns logical true (`1`) if any of the elements of `A` are nonzero, and returns logical false (`0`) if all the elements are zero.

If `A` is a matrix, `any(A)` treats the columns of `A` as vectors, returning a row vector of `1`s and `0`s.

If `A` is a multidimensional array, `any(A)` treats the values along the first non-singleton dimension as vectors, returning a logical condition for each vector.

`B = any(A,`*`dim`*`)` tests along the dimension of `A` specified by scalar *`dim`*.

1	0	1
0	0	0

A

1	0	1

any(A,1)

1
0

any(A,2)

Examples

Given,

```
A = [0.53 0.67 0.01 0.38 0.07 0.42 0.69]
```

then `B = (A < 0.5)` returns logical true (`1`) only where `A` is less than one half:

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

The `any` function reduces such a vector of logical conditions to a single condition. In this case, `any(B)` yields `1`.

This makes `any` particularly useful in `if` statements,

```
if any(A < 0.5)
    do something
end
```

where code is executed depending on a single condition, not a vector of possibly conflicting conditions.

Applying the `any` function twice to a matrix, as in `any(any(A))`, always reduces it to a scalar condition.

```
any(any(eye(3)))
ans =
   1
```

See Also

`all`, `logical operators`, `relational operators`, `colon`

Other functions that collapse an array's dimensions include:

`max`, `mean`, `median`, `min`, `prod`, `std`, `sum`, `trapz`

area

Purpose Area fill of a two-dimensional plot

Syntax

```
area(Y)
area(X,Y)
area(...,ymin)
area(...,'PropertyName',PropertyValue,...)
h = area(...)
```

Description An area plot displays elements in `Y` as one or more curves and fills the area beneath each curve. When `Y` is a matrix, the curves are stacked showing the relative contribution of each row element to the total height of the curve at each *x* interval.

`area(Y)` plots the vector `Y` or the sum of each column in matrix `Y`. The *x*-axis automatically scales depending on `length(Y)` when `Y` is a vector and on `size(Y,1)`when `Y` is a matrix.

`area(X,Y)` plots `Y` at the corresponding values of `X`. If `X` is a vector, `length(X)` must equal `length(Y)` and `X` must be monotonic. If `X` is a matrix, `size(X)` must equal `size(Y)` and each column in `X` must be monotonic. To make a vector or matrix monotonic, use `sort`.

`area(...,ymin)` specifies the lower limit in the *y* direction for the area fill. The default `ymin` is `0`.

`area(...,'`*`PropertyName`*`',PropertyValue,...)` specifies property name and property value pairs for the patch graphics object created by `area`.

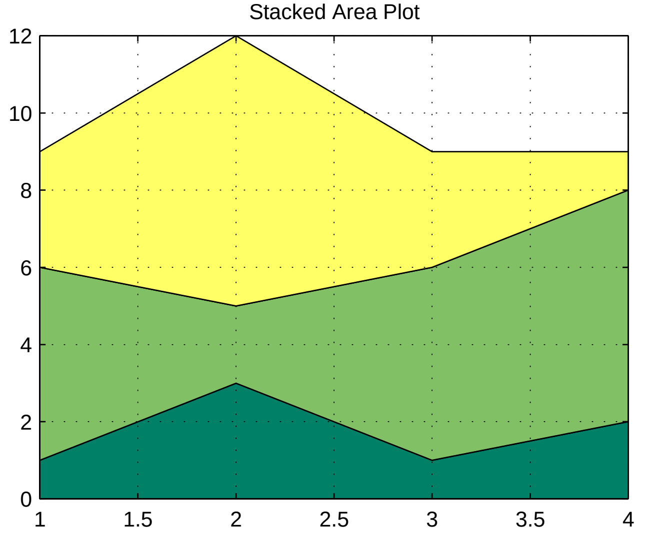
`h = area(...)` returns handles of patch graphics objects. `area` creates one patch object per column in `Y`.

Remarks `area` creates one curve from all elements in a vector or one curve per column in a matrix. The colors of the curves are selected from equally spaced intervals throughout the entire range of the colormap.

Examples Plot the values in `Y` as a stacked area plot.

```
Y = [  1, 5, 3;
       3, 2, 7;
```

```
        1, 5, 3;
        2, 6, 1];
area(Y)
grid on
colormap summer
set(gca,'Layer','top')
title 'Stacked Area Plot'
```



See Also

`plot`

“Area, Bar, and Pie Plots” for related functions

Area Graphs for more examples

Purpose Inverse secant

Syntax

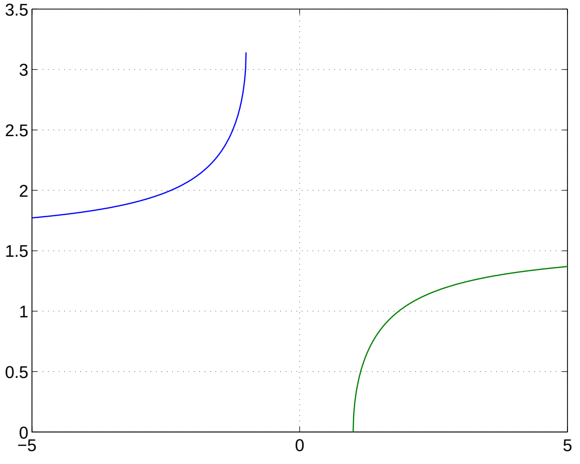
```
Y = asec(X)
```

Description `Y = asec(X)` returns the inverse secant (arcsecant) for each element of `X`.

The asec function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples Graph the inverse secant over the domains $1 \le x \le 5$ and $-5 \le x \le -1$.

```
x1 = -5:0.01:-1;
x2 = 1:0.01:5;
plot(x1,asec(x1),x2,asec(x2)), grid on
```



Definition The inverse secant can be defined as

$$\sec^{-1}(z) = \cos^{-1}\left(\frac{1}{z}\right)$$

Algorithm asec uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also asech, sec

Purpose Inverse hyperbolic secant

Syntax

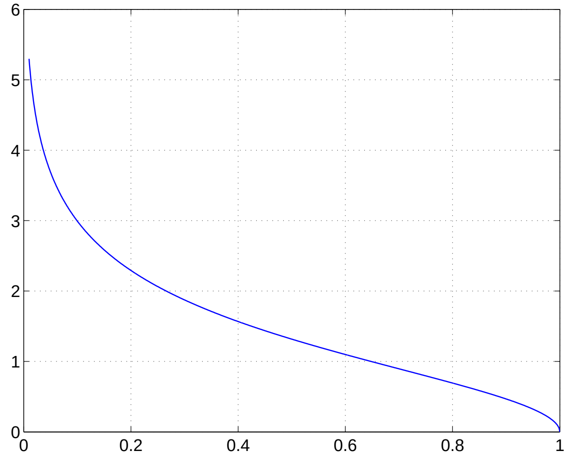
```
Y = asech(X)
```

Description `Y = asech(X)` returns the inverse hyperbolic secant for each element of `X`.

The `asech` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples Graph the inverse hyperbolic secant over the domain $0.01 \le x \le 1$.

```
x = 0.01:0.001:1;
plot(x,asech(x)), grid on
```



Definition The hyperbolic inverse secant can be defined as

$$\operatorname{sech}^{-1}(z) = \cosh^{-1}\left(\frac{1}{z}\right)$$

Algorithm `asech` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also asec, sech

Purpose

Inverse sine

Syntax

```
Y = asin(X)
```

Description

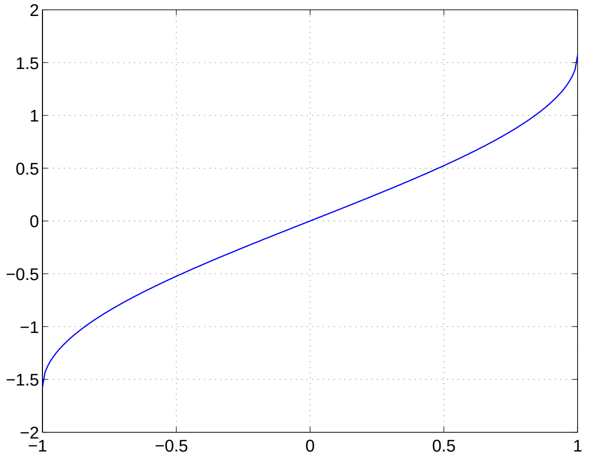
`Y = asin(X)` returns the inverse sine (arcsine) for each element of `X`. For real elements of `X` in the domain $[-1, 1]$, `asin(X)` is in the range $[-\pi/2, \pi/2]$. For real elements of `x` outside the range $[-1, 1]$, `asin(X)` is complex.

The `asin` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples

Graph the inverse sine function over the domain $-1 \le x \le 1$.

```
x = -1:.01:1;
plot(x,asin(x)), grid on
```



Definition

The inverse sine can be defined as

$$\sin^{-1}(z) = -i\log\left[iz + (1-z^2)^{\frac{1}{2}}\right]$$

Algorithm

`asin` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also

`sin`, `asinh`

asinh

Purpose

Inverse hyperbolic sine

Syntax

```
Y = asinh(X)
```

Description

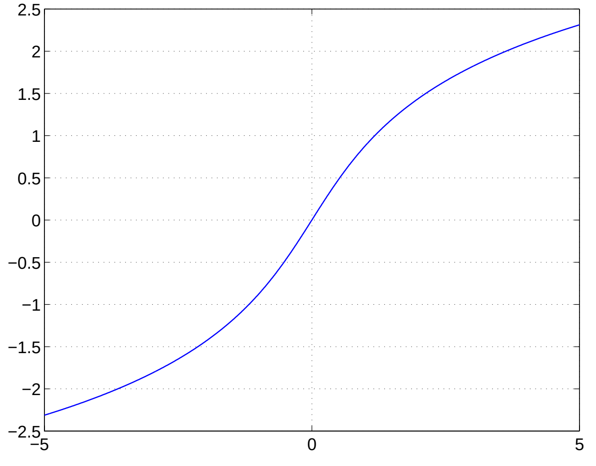
`Y = asinh(X)` returns the inverse hyperbolic sine for each element of `X`.

The `asinh` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples

Graph the inverse hyperbolic sine function over the domain $-5 \le x \le 5$.

```
x = -5:.01:5;
plot(x,asinh(x)), grid on
```



Definition

The hyperbolic inverse sine can be defined as

$$\sinh^{-1}(z) = \log\left[z + (z^2 + 1)^{\frac{1}{2}}\right]$$

Algorithm

`asinh` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also

`asin`, `sinh`

assignin

Purpose Assign a value to a workspace variable

Syntax

```
assignin(ws,'var',val)
```

Description `assignin(ws,'var',val)` assigns the value `val` to the variable *var* in the workspace `ws`. *var* is created if it doesn't exist. `ws` can have a value of `'base'` or `'caller'` to denote the MATLAB base workspace or the workspace of the caller function.

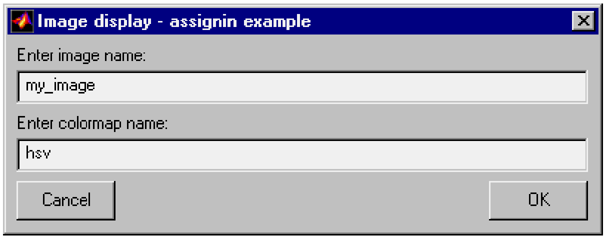
The `assignin` function is particularly useful for these tasks:

- Exporting data from a function to the MATLAB workspace
- Within a function, changing the value of a variable that is defined in the workspace of the caller function (such as a variable in the function argument list)

Remarks The MATLAB base workspace is the workspace that is seen from the MATLAB command line (when not in the debugger). The caller workspace is the workspace of the function that called the M-file. Note the base and caller workspaces are equivalent in the context of an M-file that is invoked from the MATLAB command line.

Examples This example creates a dialog box for the image display function, prompting a user for an image name and a colormap name. The `assignin` function is used to export the user–entered values to the MATLAB workspace variables `imfile` and `cmap`.

```
prompt = {'Enter image name:','Enter colormap name:'};
title = 'Image display - assignin example';
lines = 1;
def = {'my_image','hsv'};
answer = inputdlg(prompt,title,lines,def);
assignin('base','imfile',answer{1});
assignin('base','cmap',answer{2});
```



See Also `evalin`

Purpose Inverse tangent

Syntax

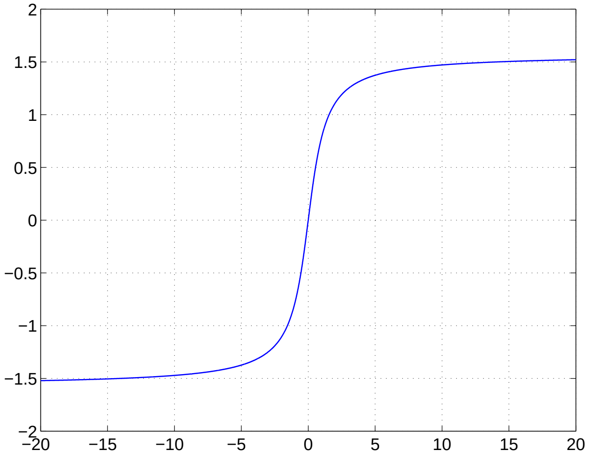
```
Y = atan(X)
```

Description `Y = atan(X)` returns the inverse tangent (arctangent) for each element of `X`. For real elements of `X`, `atan(X)` is in the range $[-\pi/2, \pi/2]$.

The `atan` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

Examples Graph the inverse tangent function over the domain $-20 \le x \le 20$.

```
x = -20:0.01:20;
plot(x,atan(x)), grid on
```



Definition The inverse tangent can be defined as

$$\tan^{-1}(z) = \frac{i}{2}\log\left(\frac{i+z}{i-z}\right)$$

Algorithm `atan` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also `atan2`, `tan`, `atanh`

atan2

Purpose

Four-quadrant inverse tangent

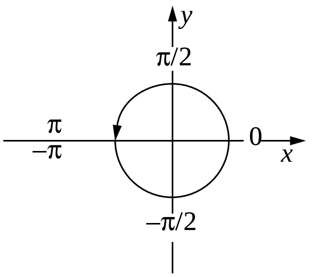
Syntax

```
P = atan2(Y,X)
```

Description

`P = atan2(Y,X)` returns an array `P` the same size as `X` and `Y` containing the element-by-element, four-quadrant inverse tangent (arctangent) of the real parts of `Y` and `X`. Any imaginary parts are ignored.

Elements of `P` lie in the closed interval `[-pi,pi]`, where `pi` is the MATLAB floating-point representation of π. `atan` uses `sign(Y)` and `sign(X)` to determine the specific quadrant.



`atan2(Y,X)` contrasts with `atan(Y/X)`, whose results are limited to the interval $[-\pi/2, \pi/2]$, or the right side of this diagram.

Examples

Any complex number $z = x + iy$ is converted to polar coordinates with

```
r = abs(z)
theta = atan2(imag(z),real(z))
```

For example,

```
z = 4 + 3i;
r = abs(z)
theta = atan2(imag(z),real(z))

r =
     5
```

```
theta =
    0.6435
```

This is a common operation, so MATLAB provides a function, `angle(z)`, that computes `theta = atan2(imag(z),real(z))`.

To convert back to the original complex number

```
z = r *exp(i *theta)
z =

   4.0000 + 3.0000i
```

Algorithm

`atan2` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also

`angle`, `atan`, `atanh`

atanh

Purpose Inverse hyperbolic tangent

Syntax

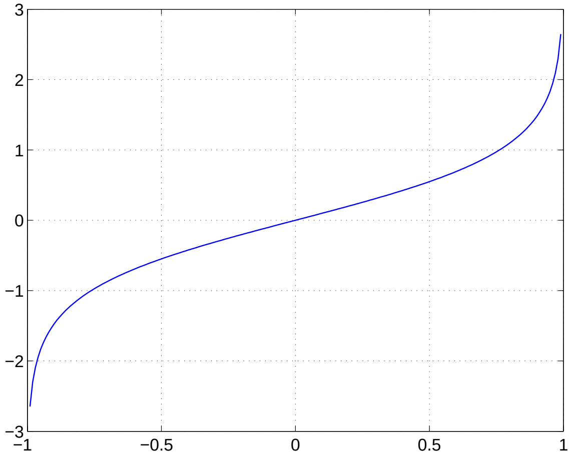
```
Y = atanh(X)
```

Description The `atanh` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

`Y = atanh(X)` returns the inverse hyperbolic tangent for each element of `X`.

Examples Graph the inverse hyperbolic tangent function over the domain $-1 < x < 1$.

```
x = -0.99:0.01:0.99;
plot(x,atanh(x)), grid on
```



Definition The hyperbolic inverse tangent can be defined as

$$\tanh^{-1}(z) = \frac{1}{2}\log\left(\frac{1+z}{1-z}\right)$$

Algorithm `atanh` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also `atan2`, `atan`, `tanh`

audiodevinfo

Purpose

Obtain information on installed audio devices

Syntax

```
d = audiodevinfo
audiodevinfo(io)
audiodevinfo(io,ID)
audiodevinfo(io,ID,'DriverVersion')
audiodevinfo(io,name)
audiodevinfo(io,rate,bits,chans)
audiodevinfo(io,ID,rate,bits,chans)
```

Description

Note This function is for use only with 32-bit, Windows-based machines.

`d = audiodevinfo` returns a structure, `d` with an input field and an output field. Each field is an array of structures that contains information about the system's audio input and output devices. Each array contains these fields: a string with the name of the device, a string with the version of the installed driver (`DriverVersion`), and the device's numeric ID.

`audiodevinfo(io)` returns the number of input (`io=1`) or output (`io=0`) audio devices on the system.

`audiodevinfo(io,ID)` returns the name of the audio device specified by its `ID`.

`audiodevinfo(io,ID,'DriverVersion')` returns a string containing the driver version of the specified audio device.

`audiodevinfo(io,name)` returns the device ID specified by `name`. You can enter a partial `name`, but the case must match. If no device with the specified name is found, `-1` is returned.

`audiodevinfo(io,rate,bits,chans)` returns the device ID of the first audio device that supports the specified sample `rate`, number of `bits`, and number of channels, `chans`. If no matching device is found, `-1` is returned.

`audiodevinfo(io,ID,rate,bits,chans)` returns `1` if the device, specified by its `ID`, supports the specified sample `rate`, number of `bits`, and number of channels, `chans`. If the device does not support the specified parameters, `0` is returned.

See Also `audioplayer`, `audiorecorder`

Purpose Create an audio player object

Syntax

```
y = audioplayer(x,Fs)
y = audioplayer(x,Fs,nbits)
y = audioplayer(r)
y = audioplayer(r,id)
```

Description

Note `audioplayer` is available only on Windows-based machines. On 32-bit, Windows-based machines with an installed 24-bit audio device, `audioplayer` supports 24-bit playback.

To use all of the `audioplayer` features, your system needs a properly installed and configured sound card with 8- and 16-bit I/O, two channels, and support for sampling rates of up to 48 kHz.

`y = audioplayer(x,Fs)` returns a handle to an audio player object `y` using input audio signal `x`. The input signal `x` can be a vector or two-dimensional array containing `single`, `double`, `int8`, `uint8`, or `int16` MATLAB data types. The input sample values for `single` and `double` data must be between -1 and 1. For `int8`, `uint8`, and `int16` data, the ranges of sample values are -128 to 127, 0 to 255, and -32768 to 32767, respectively.

`Fs` is the sampling rate in Hz to use for playback. Valid values for `Fs` depend on the specific audio hardware installed. Typical values supported by most sound cards are 8000, 11025, 22050, and 44100 Hz.

`y = audioplayer(x,Fs,nbits)` returns a handle to an audio player object where `nbits` is the bit quantization to use for `single` or `double` data types. This is an optional parameter with a default value of `16`. Valid values for `nbits` are `8` and `16` (and `24`, if a 24-bit device is installed). You do not need to specify `nbits` for `int8`, `uint8` or `int16` data because the quantization is set automatically to `8` or `16`, respectively.

`y = audioplayer(r)` returns a handle to an audio player object from an `audiorecorder` object `r`.

`y = audioplayer(r,id)` returns a handle to an audio player object from an `audiorecorder` object `r`, using the specified audio device `id` for output.

After you create an audio player object, you can use the methods listed below on that object. `y` represents the name of the returned audio player.

Method	Description

`play(y)`
`play(y,start)`
`play(y,[start stop])`
`play(y,range)`
	Starts playback from the beginning and plays to the end, or from `start` sample to the end, or from `start` sample to `stop` sample. The values of `start` and `stop` can be specified in a two-element vector `range`.

`playblocking(y)`
`playblocking(y,start)`
`playblocking(y,[start stop])`
`playblocking(y,range)`
	Same as play, but does not return control until playback completes.

`stop(y)`	Stops playback.
`pause(y)`	Pauses playback.
`resume(y)`	Restarts playback from where playback was paused.
`isplaying(y)`	Indicates whether playback is in progress. If `0`, playback is not in progress. If `1`, playback is in progress.

`display(y)`
`disp(y)`
`get(y)`
	Displays all property information about audio player `y`.

Audio player objects have the properties listed below. To set a user-settable property use this syntax:

```
set(y, 'property1', value,'property2',value,...)
```

To view a read-only property

```
get(y,’property’)          % Displays ‘property’ setting.
```

Property	Description	Type
Type	Name of the object's class	read-only
SampleRate	Sampling frequency in Hz	user-settable
BitsPerSample	Number of bits per sample	read-only
NumberOfChannels	Number of channels	read-only
TotalSamples	Total length, in samples, of the audio data	read-only
Running	Status of the audio player ('on' or 'off')	read-only
CurrentSample	Current sample being played by the audio output device (If it is not playing, currentsample is the next sample to be played with play or resume.)	read-only
UserData	User data of any type	user-settable
Tag	User-specified object label string	user-settable
For information on using the following four properties, see Creating Timer Callback Functions in the MATLAB documentation. Note that for audio object callbacks, eventStruct (event) is currently empty ([]).		
TimerFcn	Name of, or handle to, user-specified function to be called during playback	user-settable
TimerPeriod	Time, in seconds, between TimerFcn callbacks	user-settable

Property	Description	Type
StartFcn	Name of, or handle to, the function to be called once when playback starts	user-settable
StopFcn	Name of or handle to the function to be called once when playback stops	user-settable

Example

Load a sample audio file, create an audio player object, and play the audio at a higher sampling rate. x contains the audio samples and Fs is the sampling rate. You can use any of the audioplayer functions listed above on the player.

```
load handel;
player=audioplayer(y,Fs);
play(player,[1 (get(player,'SampleRate')*3)]);
```

To stop the playback, use this command:

```
stop(player);                    % Equivalent to player.stop
```

See Also

audiorecorder, sound, wavplay, wavwrite, wavread, get, set, methods

audiorecorder

Purpose

Create an audio recorder object

Syntax

```
y = audiorecorder
y = audiorecorder(Fs,nbits,channels)
y = audiorecorder(Fs,nbits,channels,id)
```

Description

Note To use all of the audio recorder object features, your system must have a properly installed and configured sound card with 8- and 16-bit I/O and support for sampling rates of up to 48 kHz.

On 32-bit, Windows-based machines with an installed 24-bit audio device, `audiorecorder` supports 24-bit recording.

`y = audiorecorder` returns a handle to an 8-kHz, 8-bit, mono audio recorder object.

`y = audiorecorder(Fs,nbits,channels)` returns a handle to an audio recorder object using the sampling `rate`, `Fs` (in Hz), the sample size of `nbits`, and the number of `channels`. `Fs` can be any sampling rate supported by the audio hardware. Common sampling rates are 8000, 11025, 22050, and 44000. The value of `nbits` must be `8` or `16` (or `24`, if a 24-bit device is installed). For mono or stereo, `channels` must be `1` or `2`, respectively.

`y = audiorecorder(Fs,nbits,channels,id)` returns a handle to an audio recorder object using the audio device specified by its `id` for input.

After you create an audio recorder object, you can use the methods listed below on that object. `y` represents the name of the returned audio recorder.

Method	Description
`record(y)` `record(y,length)`	Starts recording. Records for `length` number of seconds.
`recordblocking(y,length)`	Same as record, but does not return control until recording completes.
`stop(y)`	Stops recording.

Method	Description
`pause(y)`	Pauses recording.
`resume(y)`	Restarts recording from where recording was paused.
`isrecording(y)`	Indicates the status of recording. If `0`, recording is not in progress. If `1`, recording is in progress.
`play(y)`	Creates an `audioplayer`, plays the recorded audio data, and returns a handle to the created `audioplayer`.
`getplayer(y)`	Creates an `audioplayer` and returns a handle to the created `audioplayer`.
`getaudiodata(y)` `getaudiodata(y,'type')`	Returns the recorded audio data to the MATLAB workspace. `type` is a string containing the desired data type. Supported data types are `double`, `single`, `int16`, `int8`, or `uint8`. If `type` is omitted, it defaults to `'double'`. For `double` and `single`, the array contains values between -1 and 1. For `int8`, values are between -128 to 127. For `uint8`, values are from 0 to 255. For `int16`, values are from -32768 to 32767. If the recording is in mono, the returned array has one column. If it is in stereo, the array has two columns—one for each channel.

`display(y)`
`disp(y)`
`get(y)`
	Displays all property information about audio recorder `y`.

Audio recorder objects have the properties listed below. To set a user-settable property use this syntax:

```
set(y, 'property1', value,'property2',value,...)
```

To view a read-only property

```
get(y,’property’)         %displays ‘property’ setting.
```

Property	Description	Type
`Type`	Name of the object’s class	read-only
`SampleRate`	Sampling frequency in Hz	read-only
`BitsPerSample`	Number of bits per recorded sample	read-only
`NumberOfChannels`	Number of channels of recorded audio	read-only
`TotalSamples`	Total length, in samples, of the recording	read-only
`Running`	Status of the audio recorder ('on' or '`off`')	read-only
`CurrentSample`	Current sample being recorded by the audio output device (If it is not recording, `currentsample` is the next sample to be recorded with `record` or `resume`.)	read-only
`UserData`	User data of any type	user-settable

Property	Description	Type
For information on using the following four properties, see Creating Timer Callback Functions in the MATLAB documentation. Note that for audio object callbacks, `eventStruct` (event) is currently empty ([]).		
`TimerFcn`	Name of or handle to user-specified function to be called during recording	user-settable
`TimerPeriod`	Time, in seconds, between `TimerFcn` callbacks	user-settable
`StartFcn`	Name of or handle to the function to be called a single time when recording starts	user-settable
`StopFcn`	Name of or handle to the function to be called a single time when recording stops	user-settable
`NumberOfBuffers`	Number of buffers used for recording (You should adjust this only if you have skips, dropouts, etc. in your recording.)	user-settable
`BufferLength`	Length in seconds of buffer (You should adjust this only if you have skips, dropouts, etc. in your recording.)	user-settable
`Tag`	User-specified object label string	user-settable

Examples

Example 1

Using a microphone, record 3.5 seconds of 44.1-kHz, 16-bit, stereo data, and then return the data to the MATLAB workspace as a double array.

```
recorder = audiorecorder(44100,16,2);
recordblocking(recorder,3.5);
audioarray = getaudiodata(recorder);
```

Example 2

Using a microphone, record 8-bit, 22-kHz mono data, play it back, record again and return the data to the MATLAB workspace as a `uint8` array.

```
micrecorder = audiorecorder(22050,8,1);
record(micrecorder);
% Now, speak into microphone

stop(micrecorder);
speechplayer = play(micrecorder);
% Now, listen to the recording

stop(speechplayer);
speechdata = getaudiodata(micrecorder, 'uint8');
```

Remarks

The current implementation of `AudioRecorder` is not intended for long, high sample rate recording because it uses system memory for storage and does not use disk buffering. When large recordings are attempted, MATLAB performance may degrade.

See Also

`audioplayer`, `wavread`, `wavrecord`, `wavwrite`, `get`, `set`, `methods`

Purpose

Read NeXT/SUN (.au) sound file

Graphical Interface

As an alternative to auread, use the Import Wizard. To activate the Import Wizard, select **Import data** from the **File** menu.

Syntax

```
y = auread('aufile')
[y,Fs,bits] = auread('aufile')
[...] = auread('aufile',N)
[...] = auread('aufile',[N1,N2])
siz = auread('aufile','size')
```

Description

`y = auread('aufile')` loads a sound file specified by the string `aufile`, returning the sampled data in `y`. The `.au` extension is appended if no extension is given. Amplitude values are in the range `[-1,+1]`. `auread` supports multi-channel data in the following formats:

- 8-bit mu-law
- 8-, 16-, and 32-bit linear
- floating-point

`[y,Fs,bits] = auread('aufile')` returns the sample rate (`Fs`) in Hertz and the number of bits per sample (`bits`) used to encode the data in the file.

`[...] = auread('aufile',N)` returns only the first `N` samples from each channel in the file.

`[...] = auread('aufile',[N1 N2])` returns only samples `N1` through `N2` from each channel in the file.

`siz = auread('aufile','size')` returns the size of the audio data contained in the file in place of the actual audio data, returning the vector `siz = [samples channels]`.

See Also

`auwrite`, `wavread`

auwrite

Purpose Write NeXT/SUN (.au) sound file

Syntax

```
auwrite(y,'aufile')
auwrite(y,Fs,'aufile')
auwrite(y,Fs,N,'aufile')
auwrite(y,Fs,N,'method','aufile')
```

Description `auwrite(y,'aufile')` writes a sound file specified by the string `aufile`. The data should be arranged with one channel per column. Amplitude values outside the range `[-1,+1]` are clipped prior to writing. `auwrite` supports multi-channel data for 8-bit mu-law, and 8- and 16-bit linear formats.

`auwrite(y,Fs,'aufile')` specifies the sample rate of the data in Hertz.

`auwrite(y,Fs,N,'aufile')` selects the number of bits in the encoder. Allowable settings are `N = 8` and `N = 16`.

`auwrite(y,Fs,N,'method','aufile')` allows selection of the encoding method, which can be either `mu` or `linear`. Note that mu-law files must be 8-bit. By default, `method = 'mu'`.

See Also `auread`, `wavwrite`

Purpose Create a new Audio Video Interleaved (AVI) file

Syntax

```
aviobj = avifile(filename)
aviobj =
  avifile(filename,'PropertyName',value,'PropertyName',value,...)
```

Description `aviobj = avifile(filename)` creates an AVI file, giving it the name specified in `filename`, using default values for all AVI file object properties. If `filename` does not include an extension, `avifile` appends `.avi` to the filename. AVI is a file format for storing audio and video data.

`avifile` returns a handle to an `AVI` file object, `aviobj`. You use this object to refer to the AVI file in other functions. An AVI file object supports properties and methods that control aspects of the AVI file created.

`aviobj = avifile(filename,'Param',Value,'Param',Value,...)` creates an AVI file with the specified parameter settings. This table lists available parameters.

Parameter	Value		Default
`'colormap'`	An `m`-by-3 matrix defining the colormap to be used for indexed AVI movies, where `m` must be no greater than 256 (236 if using `Indeo` compression). You must set this parameter before calling `addframe`, unless you are using `addframe` with the MATLAB movie syntax.		There is no default colormap.
`'compression'`	A text string specifying which compression codec to use.		

	On Windows:
	`'Indeo3'`
	`'Indeo5'`
	`'Cinepak'`
	`'MSVC'`
	`'None'`
		On Unix:
		'None'
			`'Indeo3'`, on Windows. `'None'` on Unix.

Parameter	Value	Default
	To use a custom compression codec, specify the four-character code that identifies the codec (typically included in the codec documentation). The `addframe` function reports an error if it can not find the specified custom compressor.	
`'fps'`	A scalar value specifying the speed of the AVI movie in frames per second (fps).	15 fps
`'keyframe'`	For compressors that support temporal compression, this is the number of key frames per second.	2 key frames per second.
`'name'`	A descriptive name for the video stream. This parameter must be no greater than 64 characters long.	The default is the filename.
`'quality'`	A number between 0 and 100. This parameter has no effect on uncompressed movies. Higher quality numbers result in higher video quality and larger file sizes. Lower quality numbers result in lower video quality and smaller file sizes.	75

You can also use structure syntax to set AVI file object properties. For example, to set the quality property to 100 use the following syntax:

```
aviobj = avifile(filename);
aviobj.Quality = 100;
```

Example

This example shows how to use the `avifile` function to create the AVI file `example.avi`.

```
fig=figure;
set(fig,'DoubleBuffer','on');
```

```
set(gca,'xlim',[-80 80],'ylim',[-80 80],...
      'NextPlot','replace','Visible','off')
mov = avifile('example.avi')
x = -pi:.1:pi;
radius = 0:length(x);
for k=1:length(x)
   h = patch(sin(x)*radius(k),cos(x)*radius(k),...
               [abs(cos(x(k))) 0 0]);
   set(h,'EraseMode','xor');
   F = getframe(gca);
   mov = addframe(mov,F);
end
mov = close(mov);
```

See Also

`addframe`, `close`, `movie2avi`

aviinfo

Purpose Return information about an Audio Video Interleaved (AVI) file

Syntax

```
fileinfo = aviinfo(filename)
```

Description

`fileinfo = aviinfo(filename)` returns a structure whose fields contain information about the AVI file specified in the string, `filename`. If `filename` does not include an extension, then `.avi` is used. The file must be in the current working directory or in a directory on the MATLAB path.

The set of fields in the `fileinfo` structure are shown below.

Field Name	Description
`AudioFormat`	A string containing the name of the format used to store the audio data, if audio data is present
`AudioRate`	An integer indicating the sample rate in Hertz of the audio stream, if audio data is present
`Filename`	A string specifying the name of the file
`FileModDate`	A string containing the modification date of the file
`FileSize`	An integer indicating the size of the file in bytes
`FramesPerSecond`	An integer indicating the desired frames per second
`Height`	An integer indicating the height of the AVI movie in pixels
`ImageType`	A string indicating the type of image. Either `'truecolor'` for a truecolor (RGB) image, or `'indexed'` for an indexed image.
`NumAudioChannels`	An integer indicating the number of channels in the audio stream, if audio data is present
`NumFrames`	An integer indicating the total number of frames in the movie

Field Name	Description
`NumColormapEntries`	An integer specifying the number of colormap entries
`Quality`	A number between 0 and 100 indicating the video quality in the AVI file. Higher quality numbers indicate higher video quality; lower quality numbers indicate lower video quality. This value is not always set in AVI files and therefore may be inaccurate.
`VideoCompression`	A string containing the compressor used to compress the AVI file. If the compressor is not Microsoft Video 1, Run Length Encoding (RLE), Cinepak, or Intel Indeo, `aviinfo` returns a four-character code.
`Width`	An integer indicating the width of the AVI movie in pixels

See also `avifile`, `aviread`

aviread

Purpose Read an Audio Video Interleaved (AVI) file.

Syntax

```
mov = aviread(filename)
mov = aviread(filename,index)
```

Description `mov = aviread(filename)` reads the AVI movie `filename` into the MATLAB movie structure `mov`. If `filename` does not include an extension, then `.avi` is used. Use the `movie` function to view the movie, `mov`. On UNIX, `filename` must be an uncompressed AVI file.

`mov` has two fields, `cdata` and `colormap`. The content of these fields varies depending on the type of image.

Image Type	mov.cdata Field	mov.colormap Field
`Truecolor`	height-by-width-by-3 array	Empty
`Indexed`	height-by-width array	`m`-by-3 array

`mov = aviread(filename,index)` reads only the frame(s) specified by `index`. `index` can be a single index or an array of indices into the video stream. In AVI files, the first frame has the index value 1, the second frame has the index value 2, and so on.

See also `aviinfo`, `avifile`, `movie`

Purpose Create axes graphics object

Syntax

```
axes
axes('PropertyName',PropertyValue,...)
axes(h)
h = axes(...)
```

Description `axes` is the low-level function for creating axes graphics objects.

`axes` creates an axes graphics object in the current figure using default property values.

`axes('`*`PropertyName`*`',PropertyValue,...)` creates an axes object having the specified property values. MATLAB uses default values for any properties that you do not explicitly define as arguments.

`axes(h)` makes existing axes `h` the current axes. It also makes `h` the first axes listed in the figure's `Children` property and sets the figure's `CurrentAxes` property to `h`. The current axes is the target for functions that draw image, line, patch, surface, and text graphics objects.

`h = axes(...)` returns the handle of the created axes object.

Remarks MATLAB automatically creates an axes, if one does not already exist, when you issue a command that draws image, light, line, patch, surface, or text graphics objects.

The `axes` function accepts property name/property value pairs, structure arrays, and cell arrays as input arguments (see the `set` and `get` commands for examples of how to specify these data types). These properties, which control various aspects of the axes object, are described in the "Axes Properties" section.

Use the `set` function to modify the properties of an existing axes or the `get` function to query the current values of axes properties. Use the `gca` command to obtain the handle of the current axes.

The `axis` (not `axes`) function provides simplified access to commonly used properties that control the scaling and appearance of axes.

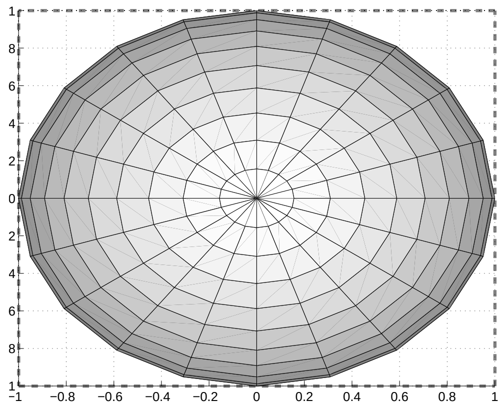
While the basic purpose of an axes object is to provide a coordinate system for plotted data, axes properties provide considerable control over the way MATLAB displays data.

Stretch-to-Fill

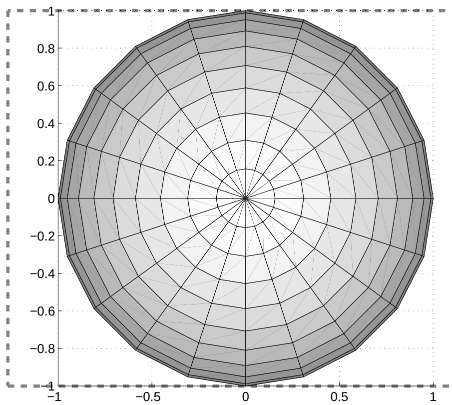
By default, MATLAB stretches the axes to fill the axes position rectangle (the rectangle defined by the last two elements in the `Position` property). This results in graphs that use the available space in the rectangle. However, some 3-D graphs (such as a sphere) appear distorted because of this stretching, and are better viewed with a specific three-dimensional aspect ratio.

Stretch-to-fill is active when the `DataAspectRatioMode`, `PlotBoxAspectRatioMode`, and `CameraViewAngleMode` are all `auto` (the default). However, stretch-to-fill is turned off when the `DataAspectRatio`, `PlotBoxAspectRatio`, or `CameraViewAngle` is user-specified, or when one or more of the corresponding modes is set to `manual` (which happens automatically when you set the corresponding property value).

This picture shows the same sphere displayed both with and without the stretch-to-fill. The dotted lines show the axes `Position` rectangle.



Stretch-to-fill active



Stretch-to-fill disabled

When stretch-to-fill is disabled, MATLAB sets the size of the axes to be as large as possible within the constraints imposed by the `Position` rectangle without introducing distortion. In the picture above, the height of the rectangle constrains the axes size.

Examples

Zooming

Zoom in using aspect ratio and limits:

```
sphere
set(gca,'DataAspectRatio',[1 1 1],...
        'PlotBoxAspectRatio',[1 1 1],'ZLim',[–0.6 0.6])
```

Zoom in and out using the CameraViewAngle:

```
sphere
set(gca,'CameraViewAngle',get(gca,'CameraViewAngle')–5)
set(gca,'CameraViewAngle',get(gca,'CameraViewAngle')+5)
```

Note that both examples disable the MATLAB stretch-to-fill behavior.

Positioning the Axes

The axes Position property enables you to define the location of the axes within the figure window. For example,

```
h = axes('Position',position_rectangle)
```

creates an axes object at the specified position within the current figure and returns a handle to it. Specify the location and size of the axes with a rectangle defined by a four-element vector,

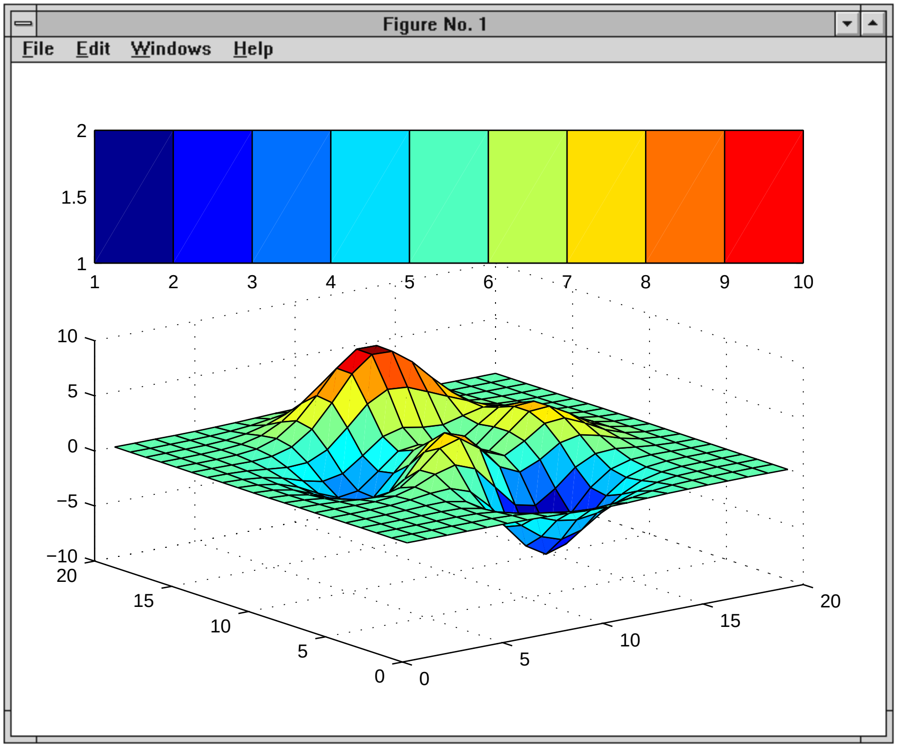
```
position_rectangle = [left, bottom, width, height];
```

The left and bottom elements of this vector define the distance from the lower-left corner of the figure to the lower-left corner of the rectangle. The width and height elements define the dimensions of the rectangle. You specify these values in units determined by the Units property. By default, MATLAB uses normalized units where (0,0) is the lower-left corner and (1.0,1.0) is the upper-right corner of the figure window.

You can define multiple axes in a single figure window:

```
axes('position',[.1  .1  .8  .6])
mesh(peaks(20));
axes('position',[.1  .7  .8  .2])
pcolor([1:10;1:10]);
```

In this example, the first plot occupies the bottom two-thirds of the figure, and the second occupies the top third.



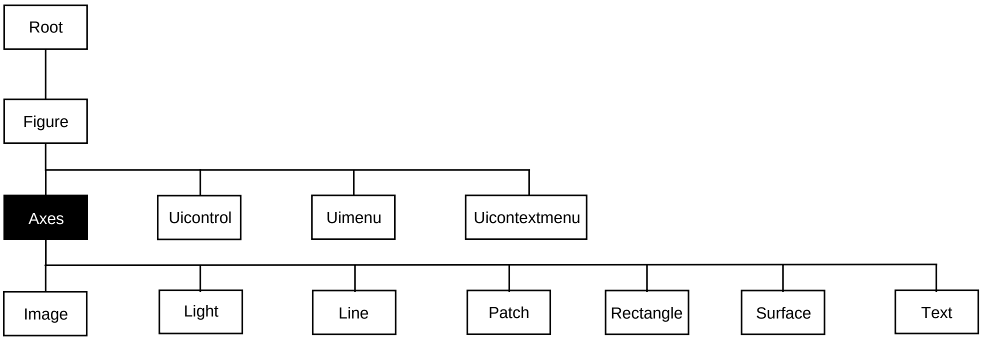
See Also

axis, cla, clf, figure, gca, grid, subplot, title, xlabel, ylabel, zlabel, view

"Axes Operations" for related functions

Axes Properties for more examples

Object Hierarchy



Setting Default Properties

You can set default axes properties on the figure and root levels:

```
set(0,'DefaultAxesPropertyName',PropertyValue,...)
set(gcf,'DefaultAxesPropertyName',PropertyValue,...)
```

where *`PropertyName`* is the name of the axes property and `PropertyValue` is the value you are specifying. Use `set` and `get` to access axes properties.

Property List

The following table lists all axes properties and provides a brief description of each. The property name links take you an expanded description of the properties.

Property Name	Property Description	Property Value
Controlling Style and Appearance		
`Box`	Toggle axes plot box on and off	Values: `on`, `off` Default: `off`
`Clipping`	This property has no effect; axes are always clipped to the figure window	
`GridLineStyle`	Line style used to draw axes grid lines	Values: `–`, `––`, `:`, `-.`, `none` Default: `:` (dotted line)

Property Name	Property Description	Property Value
MinorGridLineStyle	Line style used to draw axes minor grid lines	Values: –, ––, :, -., none Default: : (dotted line)
Layer	Draw axes above or below graphs	Values: bottom, top Default: bottom
LineStyleOrder	Sequence of line styles used for multiline plots	Values: LineSpec Default: – (solid line for)
LineWidth	Width of axis lines, in points (1/72" per point)	Values: number of points Default: 0.5 points
SelectionHighlight	Highlight axes when selected (Selected property set to on)	Values: on, off Default: on
TickDir	Direction of axis tick marks	Values: in, out Default: in (2-D), out (3-D)
TickDirMode	Use MATLAB or user-specified tick mark direction	Values: auto, manual Default: auto
TickLength	Length of tick marks normalized to axis line length, specified as two-element vector	Values: [2-D 3-D] Default: [0.01 0.025}
Visible	Make axes visible or invisible	Values: on, off Default: on
XGrid, YGrid, ZGrid	Toggle grid lines on and off in respective axis	Values: on, off Default: off
General Information About the Axes		
Children	Handles of the images, lights, lines, patches, surfaces, and text objects displayed in the axes	Values: vector of handles
CurrentPoint	Location of last mouse button click defined in the axes data units	Values: a 2-by-3 matrix

Property Name	Property Description	Property Value
HitTest	Specify whether axes can become the current object (see figure CurrentObject property)	Values: on, off Default: on
Parent	Handle of the figure window containing the axes	Values: scalar figure handle
Position	Location and size of axes within the figure	Values: [left bottom width height] Default: [0.1300 0.1100 0.7750 0.8150] in normalized Units
Selected	Indicate whether axes is in a “selected” state	Values: on, off Default: on
Tag	User-specified label	Values: any string Default: '' (empty string)
Type	The type of graphics object (read only)	Value: the string 'axes'
Units	Units used to interpret the Position property	Values: inches, centimeters, characters, normalized, points, pixels Default: normalized
UserData	User-specified data	Values: any matrix Default: [] (empty matrix)
Selecting Fonts and Labels		
FontAngle	Select italic or normal font	Values: normal, italic, oblique Default: normal
FontName	Font family name (e.g., Helvetica, Courier)	Values: a font supported by your system or the string FixedWidth Default: Typically Helvetica

Property Name	Property Description	Property Value
FontSize	Size of the font used for title and labels	Values: an integer in FontUnits Default: 10
FontUnits	Units used to interpret the FontSize property	Values: points, normalized, inches, centimeters, pixels Default: points
FontWeight	Select bold or normal font	Values: normal, bold, light, demi Default: normal
Title	Handle of the title text object	Values: any valid text object handle
XLabel, YLabel, ZLabel	Handles of the respective axis label text objects	Values: any valid text object handle
XTickLabel, YTickLabel, ZTickLabel	Specify tick mark labels for the respective axis	Values: matrix of strings Defaults: numeric values selected automatically by MATLAB
XTickLabelMode, YTickLabelMode, ZTickLabelMode	Use MATLAB or user-specified tick mark labels	Values: auto, manual Default: auto
Controlling Axis Scaling		
XAxisLocation	Specify the location of the *x*-axis	Values: top, bottom Default: bottom
YAxisLocation	Specify the location of the *y*-axis	Values: right left Default: left
XDir, YDir, ZDir	Specify the direction of increasing values for the respective axes	Values: normal, reverse Default: normal

Property Name	Property Description	Property Value
XLim, YLim, ZLim	Specify the limits to the respective axes	Values: [min max] Default: min and max determined automatically by MATLAB
XLimMode, YLimMode, ZLimMode	Use MATLAB or user-specified values for the respective axis limits	Values: auto, manual Default: auto
XMinorGrid,YMinorGrid, ZMinorGrid	Determines whether MATLAB displays gridlines connecting minor tick marks in the respective axis.	Values: on, off Default: off
XMinorTick,YMinorTick, ZMinorTick	Determines whether MATLAB displays minor tick marks in the respective axis.	Values: on, off Default: off
XScale, YScale, ZScale	Select linear or logarithmic scaling of the respective axis	Values: linear, log Default: linear (changed by plotting commands that create nonlinear plots)
XTick, YTick, ZTick	Specify the location of the axis ticks marks	Values: a vector of data values locating tick marks Default: MATLAB automatically determines tick mark placement
XTickMode, YTickMode, ZTickMode	Use MATLAB or user-specified values for the respective tick mark locations	Values: auto, manual Default: auto
Controlling the View		
CameraPosition	Specify the position of point from which you view the scene	Values: [x,y,z] axes coordinates Default: automatically determined by MATLAB

Property Name	Property Description	Property Value
CameraPositionMode	Use MATLAB or user-specified camera position	Values: auto, manual Default: auto
CameraTarget	Center of view pointed to by camera	Values: [x,y,z] axes coordinates Default: automatically determined by MATLAB
CameraTargetMode	Use MATLAB or user-specified camera target	Values: auto, manual Default: auto
CameraUpVector	Direction that is oriented up	Values: [x,y,z] axes coordinates Default: automatically determined by MATLAB
CameraUpVectorMode	Use MATLAB or user-specified camera up vector	Values: auto, manual Default: auto
CameraViewAngle	Camera field of view	Values: angle in degrees between 0 and 180 Default: automatically determined by MATLAB
CameraViewAngleMode	Use MATLAB or user-specified camera view angle	Values: auto, manual Default: auto
Projection	Select type of projection	Values: orthographic, perspective Default: orthographic
Controlling the Axes Aspect Ratio		
DataAspectRatio	Relative scaling of data units	Values: three relative values [dx dy dz] Default: automatically determined by MATLAB
DataAspectRatioMode	Use MATLAB or user-specified data aspect ratio	Values: auto, manual Default: auto

Property Name	Property Description	Property Value
PlotBoxAspectRatio	Relative scaling of axes plot box	Values: three relative values [dx dy dz] Default: automatically determined by MATLAB
PlotBoxAspectRatioMode	Use MATLAB or user-specified plot box aspect ratio	Values: auto, manual Default: auto
Controlling Callback Routine Execution		
BusyAction	Specify how to handle events that interrupt execution callback routines	Values: cancel, queue Default: queue
ButtonDownFcn	Define a callback routine that executes when a button is pressed over the axes	Values: string or function handle Default: an empty string
CreateFcn	Define a callback routine that executes when an axes is created	Values: string or function handle Default: an empty string
DeleteFcn	Define a callback routine that executes when an axes is created	Values: string or function handle Default: an empty string
Interruptible	Control whether an executing callback routine can be interrupted	Values: on, off Default: on
UIContextMenu	Associate a context menu with the axes	Values: handle of a Uicontextmenu
Specifying the Rendering Mode		
DrawMode	Specify the rendering method to use with the Painters renderer	Values: normal, fast Default: normal
Targeting Axes for Graphics Display		
HandleVisibility	Control access to a specific axes' handle	Values: on, callback, off Default: on

Property Name	Property Description	Property Value
NextPlot	Determine the eligibility of the axes for displaying graphics	Values: add, replace, replacechildren Default: replace
Properties that Specify Transparency		
ALim	Alpha axis limits	Values: [amin amax]
ALimMode	Alpha axis limits mode	Values: auto | manual Default: auto
Properties that Specify Color		
AmbientLightColor	Color of the background light in a scene	Values: ColorSpec Default: [1 1 1]
CLim	Control how data is mapped to colormap	Values: [cmin cmax] Default: automatically determined by MATLAB
CLimMode	Use MATLAB or user-specified values for CLim	Values: auto, manual Default: auto
Color	Color of the axes background	Values: none, ColorSpec Default: none
ColorOrder	Line colors used for multiline plots	Values: m-by-3 matrix of RGB values Default: depends on color scheme used
XColor, YColor, ZColor	Colors of the axis lines and tick marks	Values: ColorSpec Default: depends on current color scheme

Modifying Properties

You can set and query graphics object properties in two ways:

- The Property Editor is an interactive tool that enables you to see and change object property values.
- The `set` and `get` commands enable you to set and query the values of properties

To change the default value of properties see Setting Default Property Values.

Axes Property Descriptions

This section lists property names along with the types of values each accepts. Curly braces { } enclose default values.

`ALim` `[amin, amax]`

Alpha axis limits. A two-element vector that determines how MATLAB maps the `AlphaData` values of surface, patch and image objects to the figure's alphamap. `amin` is the value of the data mapped to the first alpha value in the alphamap, and `amax` is the value of the data mapped to the last alpha value in the alphamap. Data values in between are linearly interpolated across the alphamap, while data values outside are clamped to either the first or last alphamap value, whichever is closest.

When `ALimMode` is `auto` (the default), MATLAB assigns `amin` the minimum data value and `amax` the maximum data value in the graphics object's `AlphaData`. This maps `AlphaData` elements with minimum data values to the first alphamap entry and those with maximum data values to the last alphamap entry. Data values in between are mapped linearly to the values

If the axes contains multiple graphics objects, MATLAB sets `ALim` to span the range of all objects' `AlphaData` (or `FaceVertexAlphaData` for patch objects).

`ALimMode` `{auto} | manual`

Alpha axis limits mode. In `auto` mode, MATLAB sets the `ALim` property to span the `AlphaData` limits of the graphics objects displayed in the axes. If `ALimMode` is manual, MATLAB does not change the value of `ALim` when the `AlphaData` limits of axes children change. Setting the `ALim` property sets `ALimMode` to manual.

`AmbientLightColor` `ColorSpec`

The background light in a scene. Ambient light is a directionless light that shines uniformly on all objects in the axes. However, if there are no visible light objects in the axes, MATLAB does not use `AmbientLightColor`. If there are light objects in the axes, the `AmbientLightColor` is added to the other light sources.

AspectRatio (Obsolete)

This property produces a warning message when queried or changed. It has been superseded by the `DataAspectRatio[Mode]` and `PlotBoxAspectRatio[Mode]` properties.

Box `on | {off}`

Axes box mode. This property specifies whether to enclose the axes extent in a box for 2-D views or a cube for 3-D views. The default is to not display the box.

BusyAction `cancel | {queue}`

Callback routine interruption. The `BusyAction` property enables you to control how MATLAB handles events that potentially interrupt executing callback routines. If there is a callback routine executing, subsequently invoked callback routines always attempt to interrupt it. If the `Interruptible` property of the object whose callback is executing is set to `on` (the default), then interruption occurs at the next point where the event queue is processed. If the `Interruptible` property is `off`, the `BusyAction` property (of the object owning the executing callback) determines how MATLAB handles the event. The choices are:

- `cancel` – discard the event that attempted to execute a second callback routine.
- `queue` – queue the event that attempted to execute a second callback routine until the current callback finishes.

ButtonDownFcn string or function handle

Button press callback routine. A callback routine that executes whenever you press a mouse button while the pointer is within the axes, but not over another graphics object displayed in the axes. For 3-D views, the active area is defined by a rectangle that encloses the axes.

Define this routine as a string that is a valid MATLAB expression or the name of an M-file. The expression executes in the MATLAB workspace.

See Function Handle Callbacks for information on how to use function handles to define the callback function.

CameraPosition [x, y, z] axes coordinates

The location of the camera. This property defines the position from which the camera views the scene. Specify the point in axes coordinates.

If you fix CameraViewAngle, you can zoom in and out on the scene by changing the CameraPosition, moving the camera closer to the CameraTarget to zoom in and farther away from the CameraTarget to zoom out. As you change the CameraPosition, the amount of perspective also changes, if Projection is perspective. You can also zoom by changing the CameraViewAngle; however, this does not change the amount of perspective in the scene.

CameraPositionMode {auto} | manual

Auto or manual CameraPosition. When set to auto, MATLAB automatically calculates the CameraPosition such that the camera lies a fixed distance from the CameraTarget along the azimuth and elevation specified by view. Setting a value for CameraPosition sets this property to manual.

CameraTarget [x, y, z] axes coordinates

Camera aiming point. This property specifies the location in the axes that the camera points to. The CameraTarget and the CameraPosition define the vector (the view axis) along which the camera looks.

CameraTargetMode {auto} | manual

Auto or manual CameraTarget placement. When this property is auto, MATLAB automatically positions the CameraTarget at the centroid of the axes plotbox. Specifying a value for CameraTarget sets this property to manual.

CameraUpVector [x, y, z] axes coordinates

Camera rotation. This property specifies the rotation of the camera around the viewing axis defined by the CameraTarget and the CameraPosition properties. Specify CameraUpVector as a three-element array containing the *x*, *y*, and *z* components of the vector. For example, [0 1 0] specifies the positive *y*-axis as the up direction.

The default CameraUpVector is [0 0 1], which defines the positive *z*-axis as the up direction.

CameraUpVectorMode auto} | manual

Default or user-specified up vector. When CameraUpVectorMode is auto, MATLAB uses a value of [0 0 1] (positive *z*-direction is up) for 3-D views and

[0 1 0] (positive *y*-direction is up) for 2-D views. Setting a value for CameraUpVector sets this property to manual.

CameraViewAngle scalar greater than 0 and less than or equal to 180 (angle in degrees)

The field of view. This property determines the camera field of view. Changing this value affects the size of graphics objects displayed in the axes, but does not affect the degree of perspective distortion. The greater the angle, the larger the field of view, and the smaller objects appear in the scene.

CameraViewAngleMode{auto} | manual

Auto or manual CameraViewAngle. When in auto mode, MATLAB sets CameraViewAngle to the minimum angle that captures the entire scene (up to 180°).

The following table summarizes MATLAB automatic camera behavior.

CameraView Angle	Camera Target	Camera Position	Behavior
auto	auto	auto	CameraTarget is set to plot box centroid, CameraViewAngle is set to capture entire scene, CameraPosition is set along the view axis.
auto	auto	manual	CameraTarget is set to plot box centroid, CameraViewAngle is set to capture entire scene.
auto	manual	auto	CameraViewAngle is set to capture entire scene, CameraPosition is set along the view axis.
auto	manual	manual	CameraViewAngle is set to capture entire scene.
manual	auto	auto	CameraTarget is set to plot box centroid, CameraPosition is set along the view axis.
manual	auto	manual	CameraTarget is set to plot box centroid
manual	manual	auto	CameraPosition is set along the view axis.
manual	manual	manual	All Camera properties are user-specified.

Children vector of graphics object handles

Children of the axes. A vector containing the handles of all graphics objects rendered within the axes (whether visible or not). The graphics objects that can be children of axes are images, lights, lines, patches, surfaces, and text. You can change the order of the handles and thereby change the stacking of the objects on the display.

The text objects used to label the *x*-, *y*-, and *z*-axes are also children of axes, but their `HandleVisibility` properties are set to `callback`. This means their handles do not show up in the axes `Children` property unless you set the Root `ShowHiddenHandles` property to `on`.

CLim `[cmin, cmax]`

Color axis limits. A two-element vector that determines how MATLAB maps the `CData` values of surface and patch objects to the figure's colormap. `cmin` is the value of the data mapped to the first color in the colormap, and `cmax` is the value of the data mapped to the last color in the colormap. Data values in between are linearly interpolated across the colormap, while data values outside are clamped to either the first or last colormap color, whichever is closest.

When `CLimMode` is `auto` (the default), MATLAB assigns `cmin` the minimum data value and `cmax` the maximum data value in the graphics object's `CData`. This maps `CData` elements with minimum data value to the first colormap entry and with maximum data value to the last colormap entry.

If the axes contains multiple graphics objects, MATLAB sets `CLim` to span the range of all objects' `CData`.

CLimMode `{auto} | manual`

Color axis limits mode. In `auto` mode, MATLAB sets the `CLim` property to span the `CData` limits of the graphics objects displayed in the axes. If `CLimMode` is `manual`, MATLAB does not change the value of `CLim` when the `CData` limits of axes children change. Setting the `CLim` property sets this property to `manual`.

Clipping `{on} | off`

This property has no effect on axes.

Color {none} | ColorSpec

Color of the axes back planes. Setting this property to none means the axes is transparent and the figure color shows through. A ColorSpec is a three-element RGB vector or one of the MATLAB predefined names. Note that while the default value is none, the matlabrc.m file may set the axes color to a specific color.

ColorOrder m-by-3 matrix of RGB values

Colors to use for multiline plots. ColorOrder is an *m*-by-3 matrix of RGB values that define the colors used by the plot and plot3 functions to color each line plotted. If you do not specify a line color with plot and plot3, these functions cycle through the ColorOrder to obtain the color for each line plotted. To obtain the current ColorOrder, which may be set during startup, get the property value:

```
get(gca,'ColorOrder')
```

Note that if the axes NextPlot property is set to replace (the default), high-level functions like plot reset the ColorOrder property before determining the colors to use. If you want MATLAB to use a ColorOrder that is different from the default, set NextPlot to replacechildren. You can also specify your own default ColorOrder.

CreateFcn string or function handle

Callback routine executed during object creation. This property defines a callback routine that executes when MATLAB creates an axes object. You must define this property as a default value for axes. For example, the statement,

```
set(0,'DefaultAxesCreateFcn','set(gca,''Color'',''b'')')
```

defines a default value on the Root level that sets the current axes' background color to blue whenever you (or MATLAB) create an axes. MATLAB executes this routine after setting all properties for the axes. Setting this property on an existing axes object has no effect.

The handle of the object whose CreateFcn is being executed is accessible only through the Root CallbackObject property, which can be queried using gcbo.

See Function Handle Callbacks for information on how to use function handles to define the callback function.

`CurrentPoint` 2-by-3 matrix

Location of last button click, in axes data units. A 2-by-3 matrix containing the coordinates of two points defined by the location of the pointer. These two points lie on the line that is perpendicular to the plane of the screen and passes through the pointer. The 3-D coordinates are the points, in the axes coordinate system, where this line intersects the front and back surfaces of the axes volume (which is defined by the axes *x*, *y*, and *z* limits).

The returned matrix is of the form:

$$\begin{bmatrix} x_{back} & y_{back} & z_{back} \\ x_{front} & y_{front} & z_{front} \end{bmatrix}$$

MATLAB updates the `CurrentPoint` property whenever a button-click event occurs. The pointer does not have to be within the axes, or even the figure window; MATLAB returns the coordinates with respect to the requested axes regardless of the pointer location.

`DataAspectRatio` `[dx dy dz]`

Relative scaling of data units. A three-element vector controlling the relative scaling of data units in the *x*, *y*, and *z* directions. For example, setting this property t o `[1 2 1]` causes the length of one unit of data in the *x* direction to be the same length as two units of data in the *y* direction and one unit of data in the *z* direction.

Note that the `DataAspectRatio` property interacts with the `PlotBoxAspectRatio`, `XLimMode`, `YLimMode`, and `ZLimMode` properties to control how MATLAB scales the *x*-, *y*-, and *z*-axis. Setting the `DataAspectRatio` will disable the stretch-to-fill behavior, if `DataAspectRatioMode`, `PlotBoxAspectRatioMode`, and `CameraViewAngleMode` are all `auto`. The following table describes the interaction between properties when `stretch-to-fill` behavior is disabled.

X-, Y-, Z-Limits	DataAspect Ratio	PlotBox AspectRatio	Behavior
`auto`	`auto`	`auto`	Limits chosen to span data range in all dimensions.
`auto`	`auto`	`manual`	Limits chosen to span data range in all dimensions. `DataAspectRatio` is modified to achieve the requested `PlotBoxAspectRatio` within the limits selected by MATLAB.
`auto`	`manual`	`auto`	Limits chosen to span data range in all dimensions. `PlotBoxAspectRatio` is modified to achieve the requested `DataAspectRatio` within the limits selected by MATLAB.
`auto`	`manual`	`manual`	Limits chosen to completely fit and center the plot within the requested `PlotBoxAspectRatio` given the requested `DataAspectRatio` (this may produce empty space around 2 of the 3 dimensions).
`manual`	`auto`	`auto`	Limits are honored. The `DataAspectRatio` and `PlotBoxAspectRatio` are modified as necessary.
`manual`	`auto`	`manual`	Limits and `PlotBoxAspectRatio` are honored. The `DataAspectRatio` is modified as necessary.
`manual`	`manual`	`auto`	Limits and `DataAspectRatio` are honored. The `PlotBoxAspectRatio` is modified as necessary.
`1 manual` `2 auto`	`manual`	`manual`	The 2 automatic limits are selected to honor the specified aspect ratios and limit. See “Examples”
`2 or 3 manual`	`manual`	`manual`	Limits and `DataAspectRatio` are honored; the `PlotBoxAspectRatio` is ignored.

DataAspectRatioMode {auto} | manual

User or MATLAB controlled data scaling. This property controls whether the values of the DataAspectRatio property are user defined or selected automatically by MATLAB. Setting values for the DataAspectRatio property automatically sets this property to manual. Changing DataAspectRatioMode to manual disables the stretch-to-fill behavior, if DataAspectRatioMode, PlotBoxAspectRatioMode, and CameraViewAngleMode are all auto.

DeleteFcn string or function handle

Delete axes callback routine. A callback routine that executes when the axes object is deleted (e.g., when you issue a delete or a close command). MATLAB executes the routine before destroying the object's properties so the callback routine can query these values.

The handle of the object whose DeleteFcn is being executed is accessible only through the Root CallbackObject property, which can be queried using gcbo.

See Function Handle Callbacks for information on how to use function handles to define the callback function.

DrawMode {normal} | fast

Rendering method. This property controls the method MATLAB uses to render graphics objects displayed in the axes, when the figure Renderer property is painters.

- normal mode draws objects in back to front ordering based on the current view in order to handle hidden surface elimination and object intersections.
- fast mode draws objects in the order in which you specify the drawing commands, without considering the relationships of the objects in three dimensions. This results in faster rendering because it requires no sorting of objects according to location in the view, but may produce undesirable results because it bypasses the hidden surface elimination and object intersection handling provided by normal DrawMode.

When the figure Renderer is zbuffer, DrawMode is ignored, and hidden surface elimination and object intersection handling are always provided.

FontAngle {normal} | italic | oblique

Select italic or normal font. This property selects the character slant for axes text. normal specifies a nonitalic font. italic and oblique specify italic font.

FontName A name such as `Courier` or the string `FixedWidth`

Font family name. The font family name specifying the font to use for axes labels. To display and print properly, `FontName` must be a font that your system supports. Note that the *x*-, *y*-, and *z*-axis labels do not display in a new font until you manually reset them (by setting the `XLabel`, `YLabel`, and `ZLabel` properties or by using the `xlabel`, `ylabel`, or `zlabel` command). Tick mark labels change immediately.

Specifying a Fixed-Width Font

If you want an axes to use a fixed-width font that looks good in any locale, you should set `FontName` to the string `FixedWidth`:

```
set(axes_handle,'FontName','FixedWidth')
```

This eliminates the need to hardcode the name of a fixed-width font, which may not display text properly on systems that do not use ASCII character encoding (such as in Japan where multibyte character sets are used). A properly written MATLAB application that needs to use a fixed-width font should set `FontName` to `FixedWidth` (note that this string is case sensitive) and rely on `FixedWidthFontName` to be set correctly in the end-user's environment.

End users can adapt a MATLAB application to different locales or personal environments by setting the root `FixedWidthFontName` property to the appropriate value for that locale from `startup.m`.

Note that setting the root `FixedWidthFontName` property causes an immediate update of the display to use the new font.

FontSize Font size specified in `FontUnits`

Font size. An integer specifying the font size to use for axes labels and titles, in units determined by the `FontUnits` property. The default point size is 12. The *x*-, *y*-, and *z*-axis text labels do not display in a new font size until you manually reset them (by setting the `XLabel`, `YLabel`, or `ZLabel` properties or by using the `xlabel`, `ylabel`, or `zlabel` command). Tick mark labels change immediately.

FontUnits `{points} | normalized | inches | centimeters | pixels`

Units used to interpret the `FontSize` *property*. When set to `normalized`, MATLAB interprets the value of `FontSize` as a fraction of the height of the axes. For example, a normalized `FontSize` of 0.1 sets the text characters to a font whose height is one tenth of the axes' height. The default units (points), are equal to 1/72 of an inch.

FontWeight {normal} | bold | light | demi

Select bold or normal font. The character weight for axes text. The *x*-, *y*-, and *z*-axis text labels do not display in bold until you manually reset them (by setting the XLabel, YLabel, and ZLabel properties or by using the xlabel, ylabel, or zlabel commands). Tick mark labels change immediately.

GridLineStyle – | ––| {:} | –. | none

Line style used to draw grid lines. The line style is a string consisting of a character, in quotes, specifying solid lines (–), dashed lines (––), dotted lines(:), or dash-dot lines (–.). The default grid line style is dotted. To turn on grid lines, use the grid command.

HandleVisibility {on} | callback | off

Control access to object's handle by command-line users and GUIs. This property determines when an object's handle is visible in its parent's list of children. HandleVisibility is useful for preventing command-line users from accidentally drawing into or deleting a figure that contains only user interface devices (such as a dialog box).

Handles are always visible when HandleVisibility is on.

Setting HandleVisibility to callback causes handles to be visible from within callback routines or functions invoked by callback routines, but not from within functions invoked from the command line. This provides a means to protect GUIs from command-line users, while allowing callback routines to have complete access to object handles.

Setting HandleVisibility to off makes handles invisible at all times. This may be necessary when a callback routine invokes a function that might potentially damage the GUI (such as evaluating a user-typed string) and so temporarily hides its own handles during the execution of that function.

When a handle is not visible in its parent's list of children, it cannot be returned by functions that obtain handles by searching the object hierarchy or querying handle properties. This includes get, findobj, gca, gcf, gco, newplot, cla, clf, and close.

When a handle's visibility is restricted using `callback` or `off`, the object's handle does not appear in its parent's `Children` property, figures do not appear in the Root's `Currentfigure` property, objects do not appear in the Root's `CallbackObject` property or in the figure's `CurrentObject` property, and axes do not appear in their parent's `Currentaxes` property.

You can set the Root `ShowHiddenHandles` property to on to make all handles visible, regardless of their `HandleVisibility` settings (this does not affect the values of the `HandleVisibility` properties).

Handles that are hidden are still valid. If you know an object's handle, you can `set` and `get` its properties, and pass it to any function that operates on handles.

`HitTest` `{on} | off`

Selectable by mouse click. `HitTest` determines if the axes can become the current object (as returned by the `gco` command and the figure `CurrentObject` property) as a result of a mouse click on the axes. If `HitTest` is `off`, clicking on the axes selects the object below it (which is usually the figure containing it).

`Interruptible` `{on} | off`

Callback routine interruption mode. The `Interruptible` property controls whether an axes callback routine can be interrupted by subsequently invoked callback routines. Only callback routines defined for the `ButtonDownFcn` are affected by the `Interruptible` property. MATLAB checks for events that can interrupt a callback routine only when it encounters a `drawnow`, `figure`, `getframe`, or `pause` command in the routine. See the `BusyAction` property for related information.

Setting `Interruptible` to `on` allows any graphics object's callback routine to interrupt callback routines originating from an axes property. Note that MATLAB does not save the state of variables or the display (e.g., the handle returned by the `gca` or `gcf` command) when an interruption occurs.

`Layer` `{bottom} | top`

Draw axis lines below or above graphics objects. This property determines if axis lines and tick marks draw on top or below axes children objects for any 2-D view (i.e., when you are looking along the x-, y-, or z-axis). This is useful for placing grid lines and tick marks on top of images.

LineStyleOrder LineSpec

Order of line styles and markers used in a plot. This property specifies which line styles and markers to use and in what order when creating multiple-line plots. For example,

```
set(gca,'LineStyleOrder', '-*|:|o')
```

sets `LineStyleOrder` to solid line with asterisk marker, dotted line, and hollow circle marker. The default is (–), which specifies a solid line for all data plotted. Alternatively, you can create a cell array of character strings to define the line styles:

```
set(gca,'LineStyleOrder',{'-*',':','o'})
```

MATLAB supports four line styles, which you can specify any number of times in any order. MATLAB cycles through the line styles only after using all colors defined by the `ColorOrder` property. For example, the first eight lines plotted use the different colors defined by `ColorOrder` with the first line style. MATLAB then cycles through the colors again, using the second line style specified, and so on.

You can also specify line style and color directly with the `plot` and `plot3` functions or by altering the properties of the line objects.

Note that, if the axes `NextPlot` property is set to `replace` (the default), high-level functions like `plot` reset the `LineStyleOrder` property before determining the line style to use. If you want MATLAB to use a `LineStyleOrder` that is different from the default, set `NextPlot` to `replacechildren`. You can also specify your own default `LineStyleOrder`.

LineWidth linewidth in points

Width of axis lines. This property specifies the width, in points, of the *x*-, *y*-, and *z*-axis lines. The default line width is 0.5 points (1 point = $^1/_{72}$ inch).

MinorGridLineStyle `- | --| {:} | -. | none`

Line style used to draw minor grid lines. The line style is a string consisting of one or more characters, in quotes, specifying solid lines (–), dashed lines (––), dotted lines(:), or dash-dot lines (–.). The default minor grid line style is dotted. To turn on minor grid lines, use the `grid minor` command.

NextPlot add | {replace} | replacechildren

Where to draw the next plot. This property determines how high-level plotting functions draw into an existing axes.

- add — use the existing axes to draw graphics objects.
- replace — reset all axes properties, except Position, to their defaults and delete all axes children before displaying graphics (equivalent to cla reset).
- replacechildren — remove all child objects, but do not reset axes properties (equivalent to cla).

The newplot function simplifies the use of the NextPlot property and is used by M-file functions that draw graphs using only low-level object creation routines. See the M-file pcolor.m for an example. Note that figure graphics objects also have a NextPlot property.

Parent figure handle

Axes parent. The handle of the axes' parent object. The parent of an axes object is the figure in which it is displayed. The utility function gcf returns the handle of the current axes' Parent. You can reparent axes to other figure objects.

PlotBoxAspectRatio [px py pz]

Relative scaling of axes plotbox. A three-element vector controlling the relative scaling of the plot box in the *x*-, *y*-, and *z*-directions. The plot box is a box enclosing the axes data region as defined by the *x*-, *y*-, and *z*-axis limits.

Note that the PlotBoxAspectRatio property interacts with the DataAspectRatio, XLimMode, YLimMode, and ZLimMode properties to control the way graphics objects are displayed in the axes. Setting the PlotBoxAspectRatio disables stretch-to-fill behavior, if DataAspectRatioMode, PlotBoxAspectRatioMode, and CameraViewAngleMode are all auto.

PlotBoxAspectRatioMode {auto} | manual

User or MATLAB controlled axis scaling. This property controls whether the values of the PlotBoxAspectRatio property are user defined or selected automatically by MATLAB. Setting values for the PlotBoxAspectRatio property automatically sets this property to manual. Changing the PlotBoxAspectRatioMode to manual disables stretch-to-fill behavior, if

DataAspectRatioMode, PlotBoxAspectRatioMode, and CameraViewAngleMode are all auto.

Position four-element vector

Position of axes. A four-element vector specifying a rectangle that locates the axes within the figure window. The vector is of the form:

```
[left bottom width height]
```

where left and bottom define the distance from the lower-left corner of the figure window to the lower-left corner of the rectangle. width and height are the dimensions of the rectangle. All measurements are in units specified by the Units property.

When axes stretch-to-fill behavior is enabled (when DataAspectRatioMode, PlotBoxAspectRatioMode, CameraViewAngleMode are all auto), the axes are stretched to fill the Position rectangle. When stretch-to-fill is disabled, the axes are made as large as possible, while obeying all other properties, without extending outside the Position rectangle

Projection {orthographic} | perspective

Type of projection. This property selects between two projection types:

- orthographic – This projection maintains the correct relative dimensions of graphics objects with regard to the distance a given point is from the viewer. Parallel lines in the data are drawn parallel on the screen.
- perspective – This projection incorporates foreshortening, which allows you to perceive depth in 2-D representations of 3-D objects. Perspective projection does not preserve the relative dimensions of objects; a distant line segment displays smaller than a nearer line segment of the same length. Parallel lines in the data may not appear parallel on screen.

Selected on | off

Is object selected. When you set this property to on, MATLAB displays selection “handles” at the corners and midpoints if the SelectionHighlight property is also on (the default). You can, for example, define the ButtonDownFcn callback routine to set this property to on, thereby indicating that the axes has been selected.

SelectionHighlight {on} | off

Objects highlight when selected. When the Selected property is on, MATLAB indicates the selected state by drawing four edge handles and four corner handles. When SelectionHighlight is off, MATLAB does not draw the handles.

Tag string (GUIDE sets this property)

User-specified object label. The Tag property provides a means to identify graphics objects with a user-specified label. This is particularly useful when constructing interactive graphics programs that would otherwise need to define object handles as global variables or pass them as arguments between callback routines.

For example, suppose you want to direct all graphics output from an M-file to a particular axes, regardless of user actions that may have changed the current axes. To do this, identify the axes with a Tag:

```
axes('Tag','Special Axes')
```

Then make that axes the current axes before drawing by searching for the Tag with findobj:

```
axes(findobj('Tag','Special Axes'))
```

TickDir in | out

Direction of tick marks. For 2-D views, the default is to direct tick marks inward from the axis lines; 3-D views direct tick marks outward from the axis line.

TickDirMode {auto} | manual

Automatic tick direction control. In auto mode, MATLAB directs tick marks inward for 2-D views and outward for 3-D views. When you specify a setting for TickDir, MATLAB sets TickDirMode to manual. In manual mode, MATLAB does not change the specified tick direction.

TickLength [2DLength 3DLength]

Length of tick marks. A two-element vector specifying the length of axes tick marks. The first element is the length of tick marks used for 2-D views and the second element is the length of tick marks used for 3-D views. Specify tick mark lengths in units normalized relative to the longest of the visible X-, Y-, or Z-axis annotation lines.

`Title` handle of text object

Axes title. The handle of the text object that is used for the axes title. You can use this handle to change the properties of the title text or you can set `Title` to the handle of an existing text object. For example, the following statement changes the color of the current title to red:

```
set(get(gca,'Title'),'Color','r')
```

To create a new title, set this property to the handle of the text object you want to use:

```
set(gca,'Title',text('String','New Title','Color','r'))
```

However, it is generally simpler to use the `title` command to create or replace an axes title:

```
title('New Title','Color','r')
```

`Type` string (read only)

Type of graphics object. This property contains a string that identifies the class of graphics object. For axes objects, `Type` is always set to '`axes`'.

`UIContextMenu` handle of a uicontextmenu object

Associate a context menu with the axes. Assign this property the handle of a Uicontextmenu object created in the axes' parent figure. Use the `uicontextmenu` function to create the context menu. MATLAB displays the context menu whenever you right-click over the axes.

`Units` `inches | centimeters | {normalized} | points | pixels | characters`

Position units. The units used to interpret the `Position` property. All units are measured from the lower-left corner of the figure window.

- `normalized` units map the lower-left corner of the figure window to (0,0) and the upper-right corner to (1.0, 1.0).
- `inches`, `centimeters`, and `points` are absolute units (one point equals $^1/_{72}$ of an inch).
- `Character` units are defined by characters from the default system font; the width of one character is the width of the letter x, the height of one character is the distance between the baselines of two lines of text.

UserData matrix

User specified data. This property can be any data you want to associate with the axes object. The axes does not use this property, but you can access it using the `set` and `get` functions.

View Obsolete

The functionality provided by the View property is now controlled by the axes camera properties – `CameraPosition`, `CameraTarget`, `CameraUpVector`, and `CameraViewAngle`. See the `view` command.

Visible `{on} | off`

Visibility of axes. By default, axes are visible. Setting this property to `off` prevents axis lines, tick marks, and labels from being displayed. The visible property does not affect children of axes.

XAxisLocation `top | {bottom}`

Location of x-axis tick marks and labels. This property controls where MATLAB displays the *x*-axis tick marks and labels. Setting this property to `top` moves the *x*-axis to the top of the plot from its default position at the bottom.

YAxisLocation `right | {left}`

Location of y-axis tick marks and labels. This property controls where MATLAB displays the *y*-axis tick marks and labels. Setting this property to `right` moves the *y*-axis to the right side of the plot from its default position on the left side. See the `plotyy` function for a simple way to use two y-axes.

Properties That Control the X-, Y-, or Z-Axis

XColor, YColor, ZColor ColorSpec

Color of axis lines. A three-element vector specifying an RGB triple, or a predefined MATLAB color string. This property determines the color of the axis lines, tick marks, tick mark labels, and the axis grid lines of the respective *x*-, *y*-, and *z*-axis. The default color axis color is black. See `ColorSpec` for details on specifying colors.

XDir, **YDir**, **ZDir** `{normal} | reverse`

Direction of increasing values. A mode controlling the direction of increasing axis values. axes form a right-hand coordinate system. By default:

- *x*-axis values increase from left to right. To reverse the direction of increasing *x* values, set this property to `reverse`.

  ```
  set(gca,'XDir','reverse')
  ```

- *y*-axis values increase from bottom to top (2-D view) or front to back (3-D view). To reverse the direction of increasing *y* values, set this property to `reverse`.

  ```
  set(gca,'YDir','reverse')
  ```

- *z*-axis values increase pointing out of the screen (2-D view) or from bottom to top (3-D view). To reverse the direction of increasing *z* values, set this property to `reverse`.

  ```
  set(gca,'ZDir','reverse')
  ```

`XGrid`, **`YGrid`**, **`ZGrid`** `on | {off}`

Axis gridline mode. When you set any of these properties to `on`, MATLAB draws grid lines perpendicular to the respective axis (i.e., along lines of constant *x*, *y*, or *z* values). Use the `grid` command to set all three properties `on` or `off` at once.

```
set(gca,'XGrid','on')
```

`XLabel`, **`YLabel`**, **`ZLabel`** handle of text object

Axis labels. The handle of the text object used to label the *x*, *y*, or *z*-axis, respectively. To assign values to any of these properties, you must obtain the handle to the text string you want to use as a label. This statement defines a text object and assigns its handle to the `XLabel` property:

```
set(get(gca,'XLabel'),'String','axis label')
```

MATLAB places the string `'axis label'` appropriately for an *x*-axis label. Any text object whose handle you specify as an `XLabel`, `YLabel`, or `ZLabel` property is moved to the appropriate location for the respective label.

Alternatively, you can use the `xlabel`, `ylabel`, and `zlabel` functions, which generally provide a simpler means to label axis lines.

`XLim`, **`YLim`**, **`ZLim`** `[minimum maximum]`

Axis limits. A two-element vector specifying the minimum and maximum values of the respective axis.

Changing these properties affects the scale of the *x*-, *y*-, or z-dimension as well as the placement of labels and tick marks on the axis. The default values for these properties are [0 1].

XLimMode, **YLimMode**, **ZLimMode** {auto} | manual

MATLAB or user-controlled limits. The axis limits mode determines whether MATLAB calculates axis limits based on the data plotted (i.e., the XData, YData, or ZData of the axes children) or uses the values explicitly set with the XLim, YLim, or ZLim property, in which case, the respective limits mode is set to manual.

XMinorGrid, YMinorGrid, ZMinorGrid on **|** **{**off**}**

Enable or disable minor gridlines. When set to on, MATLAB draws gridlines aligned with the minor tick marks of the respective axis. Note that you do not have to enable minor ticks to display minor grids.

XMinorTick, YMinorTick, ZMinorTick on **|** **{**off**}**

Enable or disable minor tick marks. When set to on, MATLAB draws tick marks between the major tick marks of the respective axis. MATLAB automaticaly determines the number of minor ticks based on the space between the major ticks.

XScale, YScale, ZScale {linear} | log

Axis scaling. Linear or logarithmic scaling for the respective axis. See also loglog, semilogx, and semilogy.

XTick, YTick, ZTick vector of data values locating tick marks

Tick spacing. A vector of *x*-, *y*-, or *z*-data values that determine the location of tick marks along the respective axis. If you do not want tick marks displayed, set the respective property to the empty vector, [ ]. These vectors must contain monotonically increasing values.

XTickLabel, YTickLabel, ZTickLabel string

Tick labels. A matrix of strings to use as labels for tick marks along the respective axis. These labels replace the numeric labels generated by MATLAB. If you do not specify enough text labels for all the tick marks, MATLAB uses all of the labels specified, then reuses the specified labels.

For example, the statement,

```
set(gca,'XTickLabel',{'One';'Two';'Three';'Four'})
```

labels the first four tick marks on the *x*-axis and then reuses the labels until all ticks are labeled.

Labels can be specified as cell arrays of strings, padded string matrices, string vectors separated by vertical slash characters, or as numeric vectors (where each number is implicitly converted to the equivalent string using `num2str`). All of the following are equivalent:

```
set(gca,'XTickLabel',{'1';'10';'100'})
set(gca,'XTickLabel','1|10|100')
set(gca,'XTickLabel',[1;10;100])
set(gca,'XTickLabel',['1  ';'10 ';'100'])
```

Note that tick labels do not interpret TeX character sequences (however, the `Title`, `XLabel`, `YLabel`, and `ZLabel` properties do).

XTickMode, YTickMode, ZTickMode `{auto} | manual`

MATLAB or user controlled tick spacing. The axis tick modes determine whether MATLAB calculates the tick mark spacing based on the range of data for the respective axis (`auto` mode) or uses the values explicitly set for any of the `XTick`, `YTick`, and `ZTick` properties (`manual` mode). Setting values for the `XTick`, `YTick`, or `ZTick` properties sets the respective axis tick mode to `manual`.

XTickLabelMode, YTickLabelMode, ZTickLabelMode `{auto} | manual`

MATLAB or user determined tick labels. The axis tick mark labeling mode determines whether MATLAB uses numeric tick mark labels that span the range of the plotted data (`auto` mode) or uses the tick mark labels specified with the `XTickLabel`, `YTickLabel`, or `ZTickLabel` property (`manual` mode). Setting values for the `XTickLabel`, `YTickLabel`, or `ZTickLabel` property sets the respective axis tick label mode to `manual`.

axis

Purpose Axis scaling and appearance

Syntax

```
axis([xmin xmax ymin ymax])
axis([xmin xmax ymin ymax zmin zmax cmin cmax])
v = axis

axis auto
axis manual
axis tight
axis fill

axis ij
axis xy

axis equal
axis image
axis square
axis vis3d
axis normal

axis off
axis on
axis(axes_handles,...)
[mode,visibility,direction] = axis('state')
```

Description

`axis` manipulates commonly used axes properties. (See Algorithm section.)

`axis([xmin xmax ymin ymax])` sets the limits for the *x*- and *y*-axis of the current axes.

`axis([xmin xmax ymin ymax zmin zmax cmin cmax])` sets the *x*-, *y*-, and *z*-axis limits and the color scaling limits (see `caxis`) of the current axes.

`v = axis` returns a row vector containing scaling factors for the *x*-, *y*-, and *z*-axis. `v` has four or six components depending on whether the current axes is 2-D or 3-D, respectively. The returned values are the current axes' `XLim`, `Ylim`, and `ZLim` properties.

`axis auto` sets MATLAB to its default behavior of computing the current axes' limits automatically, based on the minimum and maximum values of *x*, *y*, and *z* data. You can restrict this automatic behavior to a specific axis. For example, `axis 'auto x'` computes only the *x*-axis limits automatically; `axis 'auto yz'` computes the *y*- and *z*-axis limits automatically.

`axis manual` and `axis(axis)` freezes the scaling at the current limits, so that if `hold` is `on`, subsequent plots use the same limits. This sets the `XLimMode`, `YLimMode`, and `ZLimMode` properties to `manual`.

`axis tight` sets the axis limits to the range of the data.

`axis fill` sets the axis limits and `PlotBoxAspectRatio` so that the axes fill the position rectangle. This option has an effect only if `PlotBoxAspectRatioMode` or `DataAspectRatioMode` are `manual`.

`axis ij` places the coordinate system origin in the upper-left corner. The *i*-axis is vertical, with values increasing from top to bottom. The *j*-axis is horizontal with values increasing from left to right.

`axis xy` draws the graph in the default Cartesian axes format with the coordinate system origin in the lower-left corner. The *x*-axis is horizontal with values increasing from left to right. The *y*-axis is vertical with values increasing from bottom to top.

`axis equal` sets the aspect ratio so that the data units are the same in every direction. The aspect ratio of the *x*-, *y*-, and *z*-axis is adjusted automatically according to the range of data units in the *x*, *y*, and *z* directions.

`axis image` is the same as `axis equal` except that the plot box fits tightly around the data.

`axis square` makes the current axes region square (or cubed when three-dimensional). MATLAB adjusts the *x*-axis, *y*-axis, and *z*-axis so that they have equal lengths and adjusts the increments between data units accordingly.

`axis vis3d` freezes aspect ratio properties to enable rotation of 3-D objects and overrides stretch-to-fill.

axis normal automatically adjusts the aspect ratio of the axes and the relative scaling of the data units so that the plot fits the figures shape as best as possible.

axis off turns off all axis lines, tick marks, and labels.

axis on turns on all axis lines, tick marks, and labels.

axis(*axes_handles*,...) applies the axis command to the specified axes. For example, the following statements

```
h1 = subplot(221);
h2 = subplot(222);
axis([h1 h2],'square')
```

set both axes to square.

[mode,visibility,direction] = axis('state') returns three strings indicating the current setting of axes properties:

Output Argument	Strings Returned
mode	'auto' | 'manual'
visibility	'on' | 'off'
direction	'xy' | 'ij'

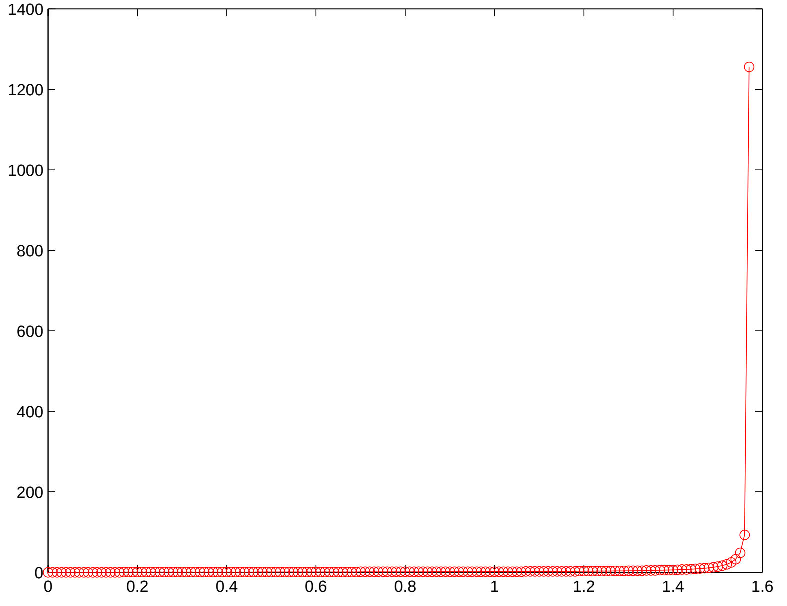
mode is auto if XLimMode, YLimMode, and ZLimMode are all set to auto. If XLimMode, YLimMode, or ZLimMode is manual, mode is manual.

Examples

The statements

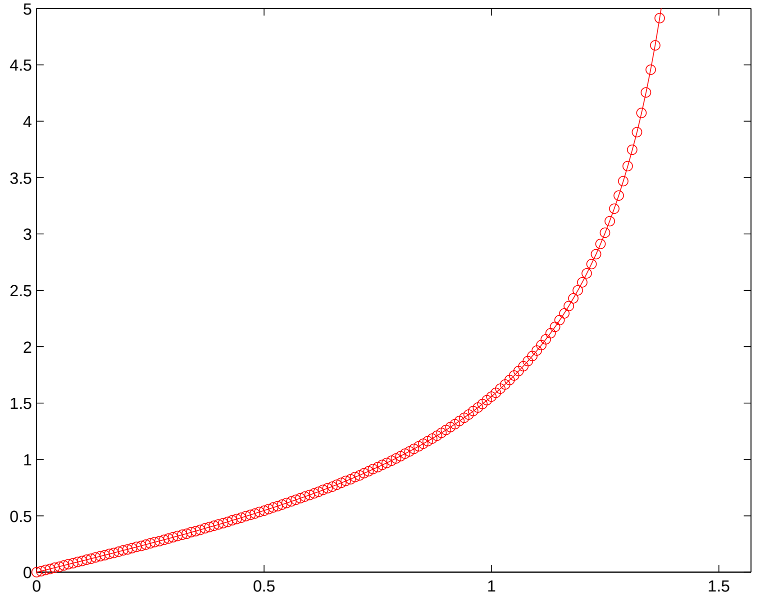
```
x = 0:.025:pi/2;
plot(x,tan(x),'-ro')
```

use the automatic scaling of the *y*-axis based on `ymax = tan(1.57)`, which is well over 1000:



The right figure shows a more satisfactory plot after typing

```
axis([0  pi/2  0  5])
```



Algorithm

When you specify minimum and maximum values for the *x*-, *y*-, and *z*-axes, `axis` sets the `XLim`, `Ylim`, and `ZLim` properties for the current axes to the respective minimum and maximum values in the argument list. Additionally, the `XLimMode`, `YLimMode`, and `ZLimMode` properties for the current axes are set to `manual`.

`axis auto` sets the current axes' `XLimMode`, `YLimMode`, and `ZLimMode` properties to `'auto'`.

`axis manual` sets the current axes' `XLimMode`, `YLimMode`, and `ZLimMode` properties to `'manual'`.

The following table shows the values of the axes properties set by `axis equal`, `axis normal`, `axis square`, and `axis image`.

Axes Property	axis equal	axis normal	axis square	axis tightequal
`DataAspectRatio`	`[1 1 1]`	`not set`	`not set`	`[1 1 1]`
`DataAspectRatioMode`	`manual`	`auto`	`auto`	`manual`
`PlotBoxAspectRatio`	`[3 4 4]`	`not set`	`[1 1 1]`	`auto`
`PlotBoxAspectRatioMode`	`manual`	`auto`	`manual`	`auto`
`Stretch-to-fill`	`disabled`	`active`	`disabled`	`disabled`

See Also

`axes`, `get`, `grid`, `set`, `subplot`

Properties of axes graphics objects

"Axes Operations" for related functions

balance

Purpose Diagonal scaling to improve eigenvalue accuracy

Syntax

```
[T,B] = balance(A)
B = balance(A)
```

Description `[T,B] = balance(A)` returns a similarity transformation `T` such that `B = T\A*T`, and `B` has approximately equal row and column norms. `T` is a permutation of a diagonal matrix whose elements are integer powers of two to prevent the introduction of round-off error. If `A` is symmetric, then `B == A` and `T` is the identity matrix.

`B = balance(A)` returns just the balanced matrix `B`.

Remarks Nonsymmetric matrices can have poorly conditioned eigenvalues. Small perturbations in the matrix, such as roundoff errors, can lead to large perturbations in the eigenvalues. The condition number of the eigenvector matrix,

```
cond(V) = norm(V)*norm(inv(V))
```

where

```
[V,T] = eig(A)
```

relates the size of the matrix perturbation to the size of the eigenvalue perturbation. Note that the condition number of `A` itself is irrelevant to the eigenvalue problem.

Balancing is an attempt to concentrate any ill conditioning of the eigenvector matrix into a diagonal scaling. Balancing usually cannot turn a nonsymmetric matrix into a symmetric matrix; it only attempts to make the norm of each row equal to the norm of the corresponding column.

Note The MATLAB eigenvalue function, `eig(A)`, automatically balances `A` before computing its eigenvalues. Turn off the balancing with `eig(A,'nobalance')`.

Examples

This example shows the basic idea. The matrix A has large elements in the upper right and small elements in the lower left. It is far from being symmetric.

```
A = [1  100  10000; .01  1  100; .0001  .01  1]
A =
   1.0e+04 *
    0.0001    0.0100    1.0000
    0.0000    0.0001    0.0100
    0.0000    0.0000    0.0001
```

Balancing produces a diagonal matrix T with elements that are powers of two and a balanced matrix B that is closer to symmetric than A.

```
[T,B] = balance(A)
T =
   1.0e+03 *
    2.0480         0         0
         0    0.0320         0
         0         0    0.0003
B =
    1.0000    1.5625    1.2207
    0.6400    1.0000    0.7813
    0.8192    1.2800    1.0000
```

To see the effect on eigenvectors, first compute the eigenvectors of A, shown here as the columns of V.

```
[V,E] = eig(A); V
V =
   -1.0000    0.9999    0.9937
    0.0050    0.0100   -0.1120
    0.0000    0.0001    0.0010
```

Note that all three vectors have the first component the largest. This indicates V is badly conditioned; in fact cond(V) is 8.7766e+003. Next, look at the eigenvectors of B.

```
[V,E] = eig(B); V
V =
   -0.8873    0.6933    0.0898
    0.2839    0.4437   -0.6482
    0.3634    0.5679   -0.7561
```

Now the eigenvectors are well behaved and `cond(V)` is `1.4421`. The ill conditioning is concentrated in the scaling matrix; `cond(T)` is `8192`.

This example is small and not really badly scaled, so the computed eigenvalues of `A` and `B` agree within roundoff error; balancing has little effect on the computed results.

Algorithm

`balance` uses LAPACK routines `DGEBAL` (real) and `ZGEBAL` (complex). If you request the output `T`, it also uses the LAPACK routines `DGEBAK` (real) and `ZGEBAK` (complex).

Limitations

Balancing can destroy the properties of certain matrices; use it with some care. If a matrix contains small elements that are due to roundoff error, balancing may scale them up to make them as significant as the other elements of the original matrix.

See Also

`eig`

References

[1] Anderson, E., Z. Bai, C. Bischof, S. Blackford, J. Demmel, J. Dongarra, J. Du Croz, A. Greenbaum, S. Hammarling, A. McKenney, and D. Sorensen, *LAPACK User's Guide* (`http://www.netlib.org/lapack/lug/lapack_lug.html`), Third Edition, SIAM, Philadelphia, 1999.

Purpose Bar chart

Syntax

```
bar(Y)
bar(x,Y)
bar(...,width)
bar(...,'style')
bar(...,LineSpec)
h = bar(...)

barh(...)
h = barh(...)
```

Description A bar chart displays the values in a vector or matrix as horizontal or vertical bars.

`bar(Y)` draws one bar for each element in `Y`. If `Y` is a matrix, `bar` groups the bars produced by the elements in each row. The *x*-axis scale ranges from 1 to `length(Y)` when `Y` is a vector, and `1` to `size(Y,1)`, which is the number of rows, when `Y` is a matrix.

`bar(x,Y)` draws a bar for each element in `Y` at locations specified in `x`, where `x` is a monotonically increasing vector defining the *x*-axis intervals for the vertical bars. If `Y` is a matrix, `bar` clusters the elements in the same row in `Y` at locations corresponding to an element in `x`.

`bar(...,width)` sets the relative bar width and controls the separation of bars within a group. The default `width` is `0.8`, so if you do not specify `x`, the bars within a group have a slight separation. If `width` is `1`, the bars within a group touch one another.

`bar(...,'style')` specifies the style of the bars. `'style'` is `'grouped'` or `'stacked'`. `'group'` is the default mode of display.

- `'grouped'` displays *n* groups of *m* vertical bars, where *n* is the number of rows and *m* is the number of columns in `Y`. The group contains one bar per column in `Y`.
- `'stacked'` displays one bar for each row in `Y`. The bar height is the sum of the elements in the row. Each bar is multi-colored, with colors corresponding

to distinct elements and showing the relative contribution each row element makes to the total sum.

`bar(...,LineSpec)` displays all bars using the color specified by `LineSpec`.

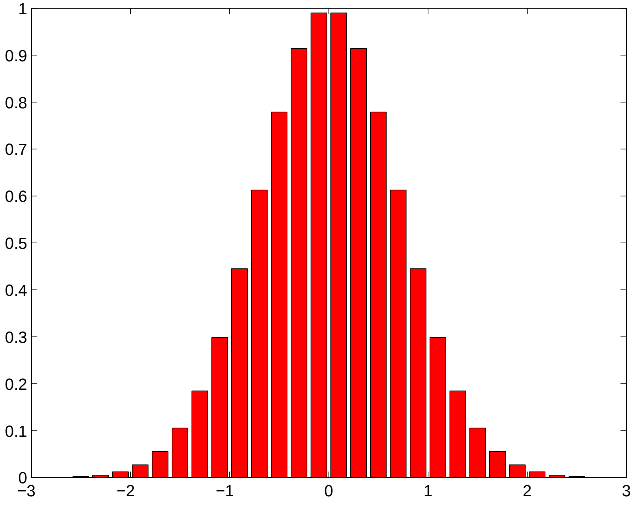
`h = bar(...)` returns a vector of handles to patch graphics objects. `bar` creates one patch graphics object per column in `Y`.

`barh(...)`, and `h = barh(...)` create horizontal bars. `Y` determines the bar length. The vector `x` is a monotonic vector defining the *y*-axis intervals for horizontal bars.

Examples

Plot a bell shaped curve:

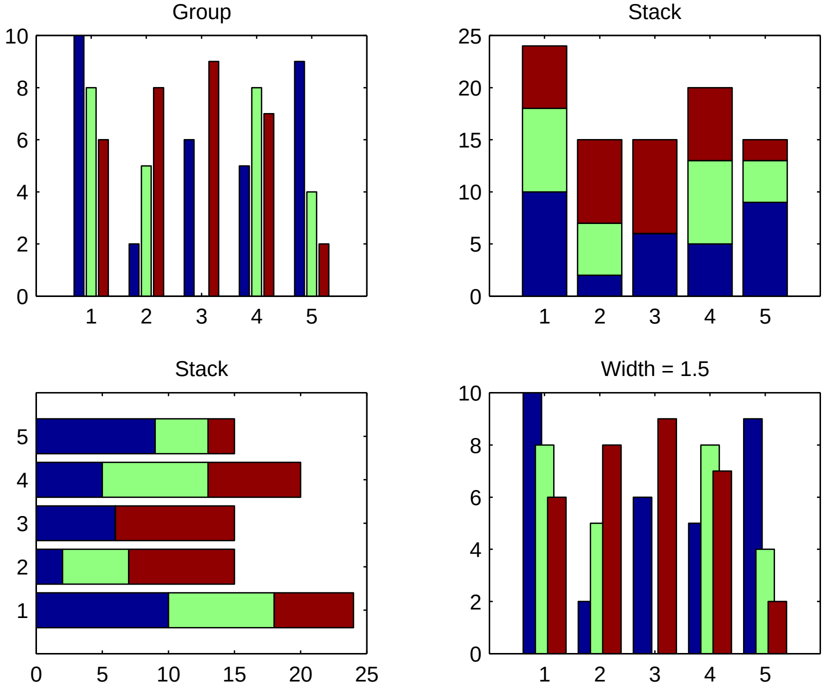
```
x = –2.9:0.2:2.9;
bar(x,exp(–x.*x))
colormap hsv
```



Create four subplots showing the effects of various `bar` arguments:

```
Y = round(rand(5,3)*10);
subplot(2,2,1)
bar(Y,'group')
title 'Group'
```

```
subplot(2,2,2)
bar(Y,'stack')
title 'Stack'

subplot(2,2,3)
barh(Y,'stack')
title 'Stack'

subplot(2,2,4)
bar(Y,1.5)
title 'Width = 1.5'
```



See Also

`bar3`, `ColorSpec`, `patch`, `stairs`, `hist`

"Area, Bar, and Pie Plots" for related functions

Bar and Area Graphs for more examples

Purpose

Three-dimensional bar chart

Syntax

```
bar3(Y)
bar3(x,Y)
bar3(...,width)
bar3(...,'style')
bar3(...,LineSpec)
h = bar3(...)

bar3h(...)
h = bar3h(...)
```

Description

`bar3` and `bar3h` draw three-dimensional vertical and horizontal bar charts.

`bar3(Y)` draws a three-dimensional bar chart, where each element in `Y` corresponds to one bar. When `Y` is a vector, the *x*-axis scale ranges from `1` to `length(Y)`. When `Y` is a matrix, the *x*-axis scale ranges from `1` to `size(Y,2)`, which is the number of columns, and the elements in each row are grouped together.

`bar3(x,Y)` draws a bar chart of the elements in `Y` at the locations specified in `x`, where `x` is a monotonic vector defining the *y*-axis intervals for vertical bars. If `Y` is a matrix, `bar3` clusters elements from the same row in `Y` at locations corresponding to an element in `x`. Values of elements in each row are grouped together.

`bar3(...,width)` sets the width of the bars and controls the separation of bars within a group. The default `width` is `0.8`, so if you do not specify `x`, bars within a group have a slight separation. If `width` is `1`, the bars within a group touch one another.

`bar3(...,'`*`style`*`')` specifies the style of the bars. `'`*`style`*`'` is `'detached'`, `'grouped'`, or `'stacked'`. `'detached'` is the default mode of display.

- `'detached'` displays the elements of each row in `Y` as separate blocks behind one another in the *x* direction.
- `'grouped'` displays *n* groups of *m* vertical bars, where *n* is the number of rows and *m* is the number of columns in `Y`. The group contains one bar per column in `Y`.

- 'stacked' displays one bar for each row in Y. The bar height is the sum of the elements in the row. Each bar is multi-colored, with colors corresponding to distinct elements and showing the relative contribution each row element makes to the total sum.

bar3(...,LineSpec) displays all bars using the color specified by LineSpec.

h = bar3(...) returns a vector of handles to patch graphics objects. bar3 creates one patch object per column in Y.

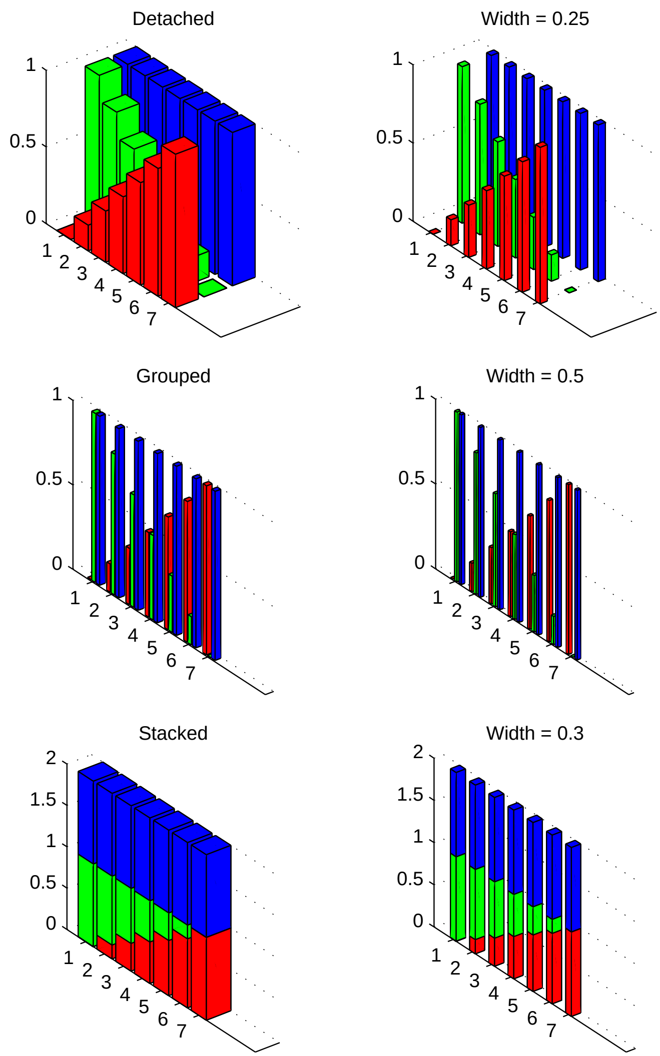
bar3h(...) and h = bar3h(...) create horizontal bars. Y determines the bar length. The vector x is a monotonic vector defining the *y*-axis intervals for horizontal bars.

Examples

This example creates six subplots showing the effects of different arguments for bar3. The data Y is a seven-by-three matrix generated using the cool colormap:

```
Y = cool(7);
subplot(3,2,1)
bar3(Y,'detached')
title('Detached')


subplot(3,2,2)
bar3(Y,0.25,'detached')
title('Width = 0.25')


subplot(3,2,3)
bar3(Y,'grouped')
title('Grouped')


subplot(3,2,4)
bar3(Y,0.5,'grouped')
title('Width = 0.5')
```

```
subplot(3,2,5)
bar3(Y,'stacked')
title('Stacked')

subplot(3,2,6)
bar3(Y,0.3,'stacked')
title('Width = 0.3')

colormap([1 0 0;0 1 0;0 0 1])
```



See Also

`bar`, `LineSpec`, `patch`

"Area, Bar, and Pie Plots" for related functions

Bar and Area Graphs for more examples

Purpose Base to decimal number conversion

Syntax

```
d = base2dec('strn',base)
```

Description `d = base2dec('strn',base)` converts the string number *strn* of the specified base into its decimal (base 10) equivalent. `base` must be an integer between 2 and 36. If *'strn'* is a character array, each row is interpreted as a string in the specified base.

Examples The expression `base2dec('212',3)` converts 212_3 to decimal, returning 23.

See Also `dec2base`

beep

Purpose

Produce a beep sound

Syntax

```
beep
beep on
beep off
s = beep
```

Description

`beep` produces you computer's default beep sound

`beep on` turns the beep on

`beep off` turn the beep off

`s = beep` returns the current beep mode (`on` or `off`)

Purpose

Bessel function of the third kind (Hankel function)

Syntax

```
H = besselh(nu,K,Z)
H = besselh(nu,Z)
H = besselh(nu,K,Z,1)
[H,ierr] = besselh(...)
```

Definitions

The differential equation

$$z^2 \frac{d^2 y}{dz^2} + z \frac{dy}{dz} + (z^2 - \nu^2)y = 0$$

where ν is a nonnegative constant, is called *Bessel's equation*, and its solutions are known as *Bessel functions*. $J_\nu(z)$ and $J_{-\nu}(z)$ form a fundamental set of solutions of Bessel's equation for noninteger ν. $Y_\nu(z)$ is a second solution of Bessel's equation – linearly independent of $J_\nu(z)$ – defined by

$$Y_\nu(z) = \frac{J_\nu(z)\cos(\nu\pi) - J_{-\nu}(z)}{\sin(\nu\pi)}$$

The relationship between the Hankel and Bessel functions is

$$H_\nu^{(1)}(z) = J_\nu(z) + i\ Y_\nu(z)$$
$$H_\nu^{(2)}(z) = J_\nu(z) - i\ Y_\nu(z)$$

where $J_\nu(z)$ is `besselj`, and $Y_\nu(z)$ is `bessely`.

Description

`H = besselh(nu,K,Z)` computes the Hankel function $H_\nu^{(K)}(z)$, where `K` = 1 or 2, for each element of the complex array `Z`. If `nu` and `Z` are arrays of the same size, the result is also that size. If either input is a scalar, `besselh` expands it to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

`H = besselh(nu,Z)` uses `K` = 1.

`H = besselh(nu,K,Z,1)` scales $H_\nu^{(K)}(z)$ by `exp(-i*Z)` if `K` = 1, and by `exp(+i*Z)` if `K` = 2.

`[H,ierr] = besselh(...)` also returns completion flags in an array the same size as `H`.

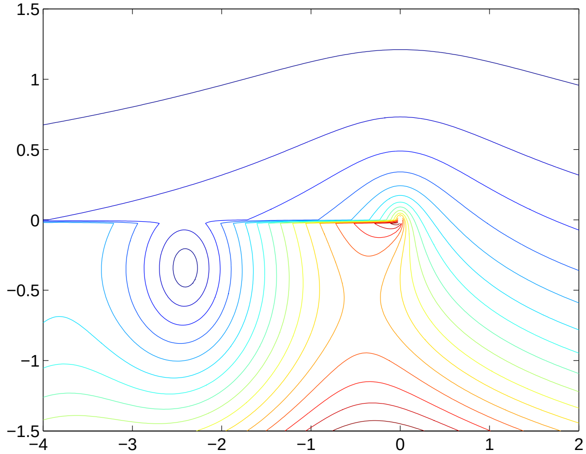
ierr	Description
0	`besselh` successfully computed the Hankel function for this element.
1	Illegal arguments.
2	Overflow. Returns `Inf`.
3	Some loss of accuracy in argument reduction.
4	Unacceptable loss of accuracy, `Z` or `nu` too large.
5	No convergence. Returns `NaN`.

Examples

This example generates the contour plots of the modulus and phase of the Hankel function $H_0^{(1)}(z)$ shown on page 359 of [1] Abramowitz and Stegun, *Handbook of Mathematical Functions*.

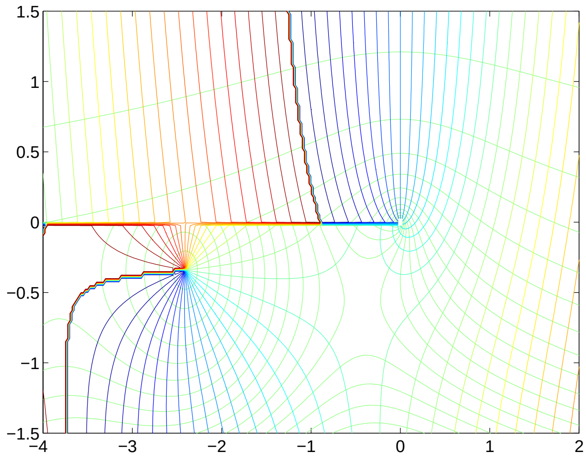
It first generates the modulus contour plot

```
[X,Y] = meshgrid(-4:0.025:2,-1.5:0.025:1.5);
H = besselh(0,1,X+i*Y);
contour(X,Y,abs(H),0:0.2:3.2), hold on
```



then adds the contour plot of the phase of the same function.

```
contour(X,Y,(180/pi)*angle(H),-180:10:180); hold off
```



See Also `besselj`, `bessely`, `besseli`, `besselk`

References

[1] Abramowitz, M. and I. A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965.

Purpose

Modified Bessel function of the first kind

Syntax

```
I = besseli(nu,Z)
I = besseli(nu,Z,1)
[I,ierr] = besseli(...)
```

Definitions

The differential equation

$$z^2\frac{d^2y}{dz^2} + z\frac{dy}{dz} - (z^2 + \nu^2)y = 0$$

where ν is a real constant, is called the *modified Bessel's equation*, and its solutions are known as *modified Bessel functions*.

$I_\nu(z)$ and $I_{-\nu}(z)$ form a fundamental set of solutions of the modified Bessel's equation for noninteger ν. $I_\nu(z)$ is defined by

$$I_\nu(z) = \left(\frac{z}{2}\right)^\nu \sum_{k=0}^{\infty} \frac{\left(\frac{z^2}{4}\right)^k}{k!\ \Gamma(\nu + k + 1)}$$

where $\Gamma(a)$ is the gamma function.

$K_\nu(z)$ is a second solution, independent of $I_\nu(z)$. It can be computed using `besselk`.

Description

`I = besseli(nu,Z)` computes the modified Bessel function of the first kind, $I_\nu(z)$, for each element of the array `Z`. The order `nu` need not be an integer, but must be real. The argument `Z` can be complex. The result is real where `Z` is positive.

If `nu` and `Z` are arrays of the same size, the result is also that size. If either input is a scalar, it is expanded to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

`I = besseli(nu,Z,1)` computes `besseli(nu,Z).*exp(-abs(real(Z)))`.

[I,ierr] = besseli(...) also returns completion flags in an array the same size as I.

ierr	Description
0	besseli succesfully computed the modified Bessel function for this element.
1	Illegal arguments.
2	Overflow. Returns Inf.
3	Some loss of accuracy in argument reduction.
4	Unacceptable loss of accuracy, Z or nu too large.
5	No convergence. Returns NaN.

Examples

Example 1.

```
format long
z = (0:0.2:1)';

besseli(1,z)

ans =
                   0
   0.10050083402813
   0.20402675573357
   0.31370402560492
   0.43286480262064
   0.56515910399249
```

Example 2. besseli(3:9,(0:.2,10)',1) generates the entire table on page 423 of [1] Abramowitz and Stegun, *Handbook of Mathematical Functions*.

Algorithm

The besseli functions uses a Fortran MEX-file to call a library developed by D. E. Amos [3] [4].

See Also

airy, besselh, besselj, besselk, bessely

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965, sections 9.1.1, 9.1.89 and 9.12, formulas 9.1.10 and 9.2.5.

[2] Carrier, Krook, and Pearson, *Functions of a Complex Variable: Theory and Technique*, Hod Books, 1983, section 5.5.

[3] Amos, D. E., "A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[4] Amos, D. E., "A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Trans. Math. Software*, 1986.

besselk

Purpose

Modified Bessel function of the second kind

Syntax

```
K = besselk(nu,Z)
K = besselk(nu,Z,1)
[K,ierr] = besselk(...)
```

Definitions

The differential equation

$$z^2\frac{d^2y}{dz^2} + z\frac{dy}{dz} - (z^2 + \nu^2)y = 0$$

where ν is a real constant, is called the *modified Bessel's equation*, and its solutions are known as *modified Bessel functions*.

A solution $K_\nu(z)$ of the second kind can be expressed as

$$K_\nu(z) = \left(\frac{\pi}{2}\right)\frac{I_{-\nu}(z) - I_\nu(z)}{\sin(\nu\pi)}$$

where $I_\nu(z)$ and $I_{-\nu}(z)$ form a fundamental set of solutions of the modified Bessel's equation for noninteger ν

$$I_\nu(z) = \left(\frac{z}{2}\right)^\nu \sum_{k=0}^{\infty}\frac{\left(\frac{z^2}{4}\right)^k}{k!\ \Gamma(\nu + k + 1)}$$

and $\Gamma(a)$ is the gamma function. $K_\nu(z)$ is independent of $I_\nu(z)$.

$I_\nu(z)$ can be computed using `besseli`.

Description

`K = besselk(nu,Z)` computes the modified Bessel function of the second kind, $K_\nu(z)$, for each element of the array `Z`. The order `nu` need not be an integer, but must be real. The argument `Z` can be complex. The result is real where `Z` is positive.

If `nu` and `Z` are arrays of the same size, the result is also that size. If either input is a scalar, it is expanded to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

K = besselk(nu,Z,1) computes besselk(nu,Z).*exp(Z).

[K,ierr] = besselk(...) also returns completion flags in an array the same size as K.

ierr	Description
0	besselk succesfully computed the modified Bessel function for this element.
1	Illegal arguments.
2	Overflow. Returns Inf.
3	Some loss of accuracy in argument reduction.
4	Unacceptable loss of accuracy, Z or nu too large.
5	No convergence. Returns NaN.

Examples

Example 1.

```
format long
z = (0:0.2:1)';

besselk(1,z)

ans =
                 Inf
   4.77597254322047
   2.18435442473269
   1.30283493976350
   0.86178163447218
   0.60190723019723
```

Example 2. besselk(3:9,(0:.2:10)',1) generates part of the table on page 424 of [1] Abramowitz and Stegun, *Handbook of Mathematical Functions*.

Algorithm

The besselk function uses a Fortran MEX-file to call a library developed by D. E. Amos [3] [4].

See Also

`airy`, `besselh`, `besseli`, `besselj`, `bessely`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965, sections 9.1.1, 9.1.89 and 9.12, formulas 9.1.10 and 9.2.5.

[2] Carrier, Krook, and Pearson, *Functions of a Complex Variable: Theory and Technique*, Hod Books, 1983, section 5.5.

[3] Amos, D. E., "A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[4] Amos, D. E., "A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order," *Trans. Math. Software*, 1986.

Purpose

Bessel function of the first kind

Syntax

```
J = besselj(nu,Z)
J = besselj(nu,Z,1)
[J,ierr] = besselj(nu,Z)
```

Definition

The differential equation

$$z^2 \frac{d^2 y}{dz^2} + z\frac{dy}{dz} + (z^2 - \nu^2)y = 0$$

where ν is a real constant, is called *Bessel's equation*, and its solutions are known as *Bessel functions*.

$J_\nu(z)$ and $J_{-\nu}(z)$ form a fundamental set of solutions of Bessel's equation for noninteger ν. $J_\nu(z)$ is defined by

$$J_\nu(z) = \left(\frac{z}{2}\right)^\nu \sum_{k=0}^{\infty} \frac{\left(-\frac{z^2}{4}\right)^k}{k!\ \Gamma(\nu + k + 1)}$$

where $\Gamma(a)$ is the gamma function.

$Y_\nu(z)$ is a second solution of Bessel's equation that is linearly independent of $J_\nu(z)$. It can be computed using `bessely`.

Description

`J = besselj(nu,Z)` computes the Bessel function of the first kind, $J_\nu(z)$, for each element of the array `Z`. The order `nu` need not be an integer, but must be real. The argument `Z` can be complex. The result is real where `Z` is positive.

If `nu` and `Z` are arrays of the same size, the result is also that size. If either input is a scalar, it is expanded to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

`J = besselj(nu,Z,1)` computes `besselj(nu,Z).*exp(-abs(imag(Z)))`.

`[J,ierr] = besselj(nu,Z)` also returns completion flags in an array the same size as `J`.

ierr	Description
0	`besselj` succesfully computed the Bessel function for this element.
1	Illegal arguments.
2	Overflow. Returns `Inf`.
3	Some loss of accuracy in argument reduction.
4	Unacceptable loss of accuracy, `Z` or `nu` too large.
5	No convergence. Returns `NaN`.

Remarks

The Bessel functions are related to the Hankel functions, also called Bessel functions of the third kind,

$$H_\nu^{(1)}(z) = J_\nu(z) + i\ Y_\nu(z)$$

$$H_\nu^{(2)}(z) = J_\nu(z) - i\ Y_\nu(z)$$

where $H_\nu^{(K)}(z)$ is `besselh`, $J_\nu(z)$ is `besselj`, and $Y_\nu(z)$ is `bessely`. The Hankel functions also form a fundamental set of solutions to Bessel's equation (see `besselh`).

Examples

Example 1.

```
format long
z = (0:0.2:1)';

besselj(1,z)

ans =
                   0
   0.09950083263924
   0.19602657795532
   0.28670098806392
   0.36884204609417
   0.44005058574493
```

Example 2. `besselj(3:9,(0:.2:10)')` generates the entire table on page 398 of [1] Abramowitz and Stegun, *Handbook of Mathematical Functions.*

Algorithm

The `besselj` function uses a Fortran MEX-file to call a library developed by D. E. Amos [3] [4].

See Also

`besselh`, `besseli`, `besselk`, `bessely`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965, sections 9.1.1, 9.1.89 and 9.12, formulas 9.1.10 and 9.2.5.

[2] Carrier, Krook, and Pearson, *Functions of a Complex Variable: Theory and Technique*, Hod Books, 1983, section 5.5.

[3] Amos, D. E., “A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order,” *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[4] Amos, D. E., “A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order,” *Trans. Math. Software*, 1986.

bessely

Purpose Bessel functions of the second kind

Syntax

```
Y = bessely(nu,Z)
Y = bessely(nu,Z,1)
[Y,ierr] = bessely(nu,Z)
```

Definition The differential equation

$$z^2\frac{d^2y}{dz^2} + z\frac{dy}{dz} + (z^2 - \nu^2)y = 0$$

where ν is a real constant, is called *Bessel's equation*, and its solutions are known as *Bessel functions*.

A solution $Y_\nu(z)$ of the second kind can be expressed as

$$Y_\nu(z) = \frac{J_\nu(z)\cos(\nu\pi) - J_{-\nu}(z)}{\sin(\nu\pi)}$$

where $J_\nu(z)$ and $J_{-\nu}(z)$ form a fundamental set of solutions of Bessel's equation for noninteger ν

$$J_\nu(z) = \left(\frac{z}{2}\right)^\nu \sum_{k=0}^{\infty} \frac{\left(-\frac{z^2}{4}\right)^k}{k!\ \Gamma(\nu + k + 1)}$$

and $\Gamma(a)$ is the gamma function. $Y_\nu(z)$ is linearly independent of $J_\nu(z)$

$J_\nu(z)$ can be computed using `besselj`.

Description `Y = bessely(nu,Z)` computes Bessel functions of the second kind, $Y_\nu(z)$, for each element of the array `Z`. The order `nu` need not be an integer, but must be real. The argument `Z` can be complex. The result is real where `Z` is positive.

If `nu` and `Z` are arrays of the same size, the result is also that size. If either input is a scalar, it is expanded to the other input's size. If one input is a row vector and the other is a column vector, the result is a two-dimensional table of function values.

`Y = bessely(nu,Z,1)` computes `bessely(nu,Z).*exp(-abs(imag(Z)))`.

`[Y,ierr] = bessely(nu,Z)` also returns completion flags in an array the same size as `Y`.

ierr	Description
0	`bessely` succesfully computed the Bessel function for this element.
1	Illegal arguments.
2	Overflow. Returns `Inf`.
3	Some loss of accuracy in argument reduction.
4	Unacceptable loss of accuracy, `Z` or `nu` too large.
5	No convergence. Returns `NaN`.

Remarks

The Bessel functions are related to the Hankel functions, also called Bessel functions of the third kind,

$$H_\nu^{(1)}(z) = J_\nu(z) + i\ Y_\nu(z)$$

$$H_\nu^{(2)}(z) = J_\nu(z) - i\ Y_\nu(z)$$

where $H_\nu^{(K)}(z)$ is `besselh`, $J_\nu(z)$ is `besselj`, and $Y_\nu(z)$ is `bessely`. The Hankel functions also form a fundamental set of solutions to Bessel's equation (see `besselh`).

Examples

Example 1.

```
format long
z = (0:0.2:1)';

bessely(1,z)

ans =
                  -Inf
  -3.32382498811185
  -1.78087204427005
```

```
-1.26039134717739
-0.97814417668336
-0.78121282130029
```

Example 2. `bessely(3:9,(0:.2:10)')` generates the entire table on page 399 of [1] Abramowitz and Stegun, *Handbook of Mathematical Functions*.

Algorithm

The `bessely` function uses a Fortran MEX-file to call a library developed by D. E Amos [3] [4].

See Also

`besselh`, `besseli`, `besselj`, `besselk`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, National Bureau of Standards, Applied Math. Series #55, Dover Publications, 1965, sections 9.1.1, 9.1.89 and 9.12, formulas 9.1.10 and 9.2.5.

[2] Carrier, Krook, and Pearson, *Functions of a Complex Variable: Theory and Technique*, Hod Books, 1983, section 5.5.

[3] Amos, D. E., “A Subroutine Package for Bessel Functions of a Complex Argument and Nonnegative Order,” *Sandia National Laboratory Report*, SAND85-1018, May, 1985.

[4] Amos, D. E., “A Portable Package for Bessel Functions of a Complex Argument and Nonnegative Order,” *Trans. Math. Software*, 1986.

Purpose Beta function

Syntax

```
B = beta(Z,W)
```

Definition The beta function is

$$B(z, w) = \int_0^1 t^{z-1}(1-t)^{w-1}\, dt = \frac{\Gamma(z)\Gamma(w)}{\Gamma(z+w)}$$

where $\Gamma(z)$ is the gamma function.

Description `B = beta(Z,W)` computes the beta function for corresponding elements of arrays `Z` and `W`. The arrays must be real and nonnegative. They must be the same size, or either can be scalar.

Examples In this example, which uses integer arguments,

```
beta(n,3)
   = (n-1)!*2!/(n+2)!
   = 2/(n*(n+1)*(n+2))
```

is the ratio of fairly small integers, and the rational format is able to recover the exact result.

```
format rat
beta((0:10)',3)

ans =

     1/0
     1/3
     1/12
     1/30
     1/60
     1/105
     1/168
     1/252
     1/360
     1/495
     1/660
```

Algorithm

```
beta(z,w) = exp(gammaln(z)+gammaln(w)-gammaln(z+w))
```

See Also

`betainc`, `betaln`, `gammaln`

Purpose Incomplete beta function

Syntax

```
I = betainc(X,Z,W)
```

Definition The incomplete beta function is

$$I_x(z, w) = \frac{1}{B(z, w)} \int_0^x t^{z-1}(1-t)^{w-1}\, dt$$

where $B(z, w)$, the beta function, is defined as

$$B(z, w) = \int_0^1 t^{z-1}(1-t)^{w-1}\, dt = \frac{\Gamma(z)\Gamma(w)}{\Gamma(z+w)}$$

and $\Gamma(z)$ is the gamma function.

Description `I = betainc(X,Z,W)` computes the incomplete beta function for corresponding elements of the arrays `X`, `Z` and `W`. The elements of `X` must be in the closed interval $[0,1]$. The arrays `Z` and `W` must be nonnegative and real. All arrays must be the same size, or any of them can be scalar.

Examples

```
format long
betainc(.5,(0:10)',3)

ans =
   1.00000000000000
   0.87500000000000
   0.68750000000000
   0.50000000000000
   0.34375000000000
   0.22656250000000
   0.14453125000000
   0.08984375000000
   0.05468750000000
   0.03271484375000
   0.01928710937500
```

See Also `beta`, `betaln`

betaln

Purpose Logarithm of beta function

Syntax `L = betaln(Z,W)`

Description `L = betaln(Z,W)` computes the natural logarithm of the beta function `log(beta(Z,W))`, for corresponding elements of arrays `Z` and `W`, without computing `beta(Z,W)`. Since the beta function can range over very large or very small values, its logarithm is sometimes more useful.

`Z` and `W` must be real and nonnegative. They must be the same size, or either can be scalar.

Examples

```
x = 510
betaln(x,x)

ans =
      -708.8616
```

`-708.8616` is slightly less than `log(realmin)`. Computing `beta(x,x)` directly would underflow (or be denormal).

Algorithm

```
betaln(z,w) = gammaln(z)+gammaln(w)-gammaln(z+w)
```

See Also `beta`, `betainc`, `gammaln`

Purpose

BiConjugate Gradients method

Syntax

```
x = bicg(A,b)
bicg(A,b,tol)
bicg(A,b,tol,maxit)
bicg(A,b,tol,maxit,M)
bicg(A,b,tol,maxit,M1,M2)
bicg(A,b,tol,maxit,M1,M2,x0)
bicg(afun,b,tol,maxit,mfun1,mfun2,x0,p1,p2,...)
[x,flag] = bicg(A,b,...)
[x,flag,relres] = bicg(A,b,...)
[x,flag,relres,iter] = bicg(A,b,...)
[x,flag,relres,iter,resvec] = bicg(A,b,...)
```

Description

`x = bicg(A,b)` attempts to solve the system of linear equations `A*x = b` for `x`. The `n`-by-`n` coefficient matrix `A` must be square and should be large and sparse. The column vector `b` must have length `n`. `A` can be a function `afun` such that `afun(x)` returns `A*x` and `afun(x,'transp')` returns `A'*x`.

If `bicg` converges, it displays a message to that effect. If `bicg` fails to converge after the maximum number of iterations or halts for any reason, it prints a warning message that includes the relative residual `norm(b-A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`bicg(A,b,tol)` specifies the tolerance of the method. If `tol` is `[]`, then `bicg` uses the default, `1e-6`.

`bicg(A,b,tol,maxit)` specifies the maximum number of iterations. If `maxit` is `[]`, then `bicg` uses the default, `min(n,20)`.

`bicg(A,b,tol,maxit,M)` and `bicg(A,b,tol,maxit,M1,M2)` use the preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. If `M` is `[]` then `bicg` applies no preconditioner. `M` can be a function `mfun` such that `mfun(x)` returns `M\x` and `mfun(x,'transp')` returns `M'\x`.

`bicg(A,b,tol,maxit,M1,M2,x0)` specifies the initial guess. If `x0` is `[]`, then `bicg` uses the default, an all-zero vector.

`bicg(afun,b,tol,maxit,m1fun,m2fun,x0,p1,p2,...)` passes parameters `p1,p2,...` to functions `afun(x,p1,p2,...)` and `afun(x,p1,p2,...,'transp')`, and similarly to the preconditioner functions `m1fun` and `m2fun`.

`[x,flag] = bicg(A,b,...)` also returns a convergence flag.

Flag	Convergence
0	`bicg` converged to the desired tolerance `tol` within `maxit` iterations.
1	`bicg` iterated `maxit` times but did not converge.
2	Preconditioner `M` was ill-conditioned.
3	`bicg` stagnated. (Two consecutive iterates were the same.)
4	One of the scalar quantities calculated during `bicg` became too small or too large to continue computing.

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = bicg(A,b,...)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, `relres <= tol`.

`[x,flag,relres,iter] = bicg(A,b,...)` also returns the iteration number at which `x` was computed, where `0 <= iter <= maxit`.

`[x,flag,relres,iter,resvec] = bicg(A,b,...)` also returns a vector of the residual norms at each iteration including `norm(b-A*x0)`.

Examples

Example 1.

```
n = 100;
on = ones(n,1);
A = spdiags([-2*on 4*on -on],-1:1,n,n);
b = sum(A,2);
tol = 1e-8;
```

```
maxit = 15;
M1 = spdiags([on/(-2) on],-1:0,n,n);
M2 = spdiags([4*on -on],0:1,n,n);

x = bicg(A,b,tol,maxit,M1,M2,[]);
```

displays this message

```
bicg converged at iteration 9 to a solution with relative
residual 5.3e-009
```

Alternatively, use this matrix-vector product function

```
function y = afun(x,n,transp_flag)
if (nargin > 2) & strcmp(transp_flag,'transp')
    y = 4 * x;
    y(1:n-1) = y(1:n-1) - 2 * x(2:n);
    y(2:n) = y(2:n) - x(1:n-1);
else
    y = 4 * x;
    y(2:n) = y(2:n) - 2 * x(1:n-1);
    y(1:n-1) = y(1:n-1) - x(2:n);
end
```

as input to `bicg`.

```
x1 = bicg(@afun,b,tol,maxit,M1,M2,[],n);
```

Example 2. This examples demonstrates the use of a preconditioner. Start with `A = west0479`, a real 479-by-479 sparse matrix, and define `b` so that the true solution is a vector of all ones.

```
load west0479;
A = west0479;
b = sum(A,2);
```

You can accurately solve `A*x = b` using backslash since `A` is not so large.

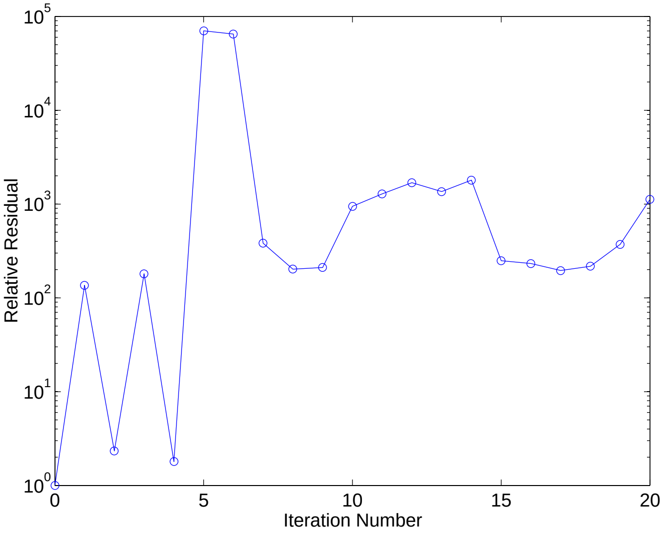
```
x = A \ b;
norm(b-A*x) / norm(b)

ans =
    8.3154e-017
```

Now try to solve `A*x = b` with `bicg`.

```
[x,flag,relres,iter,resvec] = bicg(A,b)

flag =
          1
relres =
          1
iter =
          0
```

The value of `flag` indicates that `bicg` iterated the default 20 times without converging. The value of `iter` shows that the method behaved so badly that the initial all-zero guess was better than all the subsequent iterates. The value of `relres` supports this: `relres = norm(b-A*x)/norm(b)` = `norm(b)/norm(b)` = `1`. You can confirm that the unpreconditioned method oscillates rather wildly by plotting the relative residuals at each iteration.

```
semilogy(0:20,resvec/norm(b),'-o')
xlabel('Iteration Number')
ylabel('Relative Residual')
```



Now, try an incomplete LU factorization with a drop tolerance of `1e-5` for the preconditioner.

```
[L1,U1] = luinc(A,1e-5);
Warning: Incomplete upper triangular factor has 1 zero diagonal.
         It cannot be used as a preconditioner for an iterative
         method.

nnz(A), nnz(L1), nnz(U1)

ans =
         1887
ans =
         5562
ans =
         4320
```

The zero on the main diagonal of the upper triangular `U1` indicates that `U1` is singular. If you try to use it as a preconditioner,

```
[x,flag,relres,iter,resvec] = bicg(A,b,1e-6,20,L1,U1)

flag =
         2
relres =
         1
iter =
         0
resvec =
         7.0557e+005
```

the method fails in the very first iteration when it tries to solve a system of equations involving the singular `U1` using backslash. `bicg` is forced to return the initial estimate since no other iterates were produced.

Try again with a slightly less sparse preconditioner.

```
[L2,U2] = luinc(A,1e-6);
```

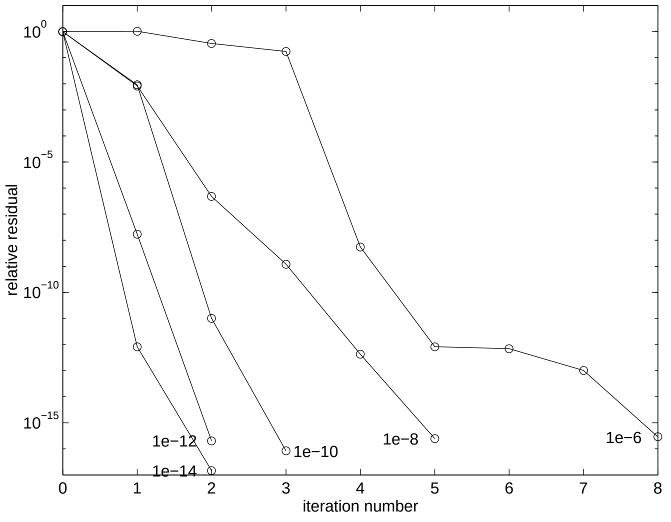
```
nnz(L2), nnz(U2)

ans =
         6231
ans =
         4559
```

This time U2 is nonsingular and may be an appropriate preconditioner.

```
[x,flag,relres,iter,resvec] = bicg(A,b,1e-15,10,L2,U2)

flag =
         0
relres =
         2.8664e-016
iter =
         8
```

and bicg converges to within the desired tolerance at iteration number 8. Decreasing the value of the drop tolerance increases the fill-in of the incomplete factors but also increases the accuracy of the approximation to the original matrix. Thus, the preconditioned system becomes closer to inv(U)*inv(L)*L*U*x = inv(U)*inv(L)*b, where L and U are the true LU factors, and closer to being solved within a single iteration.

The next graph shows the progress of bicg using six different incomplete LU factors as preconditioners. Each line in the graph is labeled with the drop tolerance of the preconditioner used in bicg.



See Also

`bicgstab`, `cgs`, `gmres`, `lsqr`, `luinc`, `minres`, `pcg`, `qmr`, `symmlq`

`@` (function handle), `\` (backslash)

References

[1] Barrett, R., M. Berry, T. F. Chan, et al., *Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods*, SIAM, Philadelphia, 1994.

bicgstab

Purpose BiConjugate Gradients Stabilized method

Syntax

```
x = bicgstab(A,b)
bicgstab(A,b,tol)
bicgstab(A,b,tol,maxit)
bicgstab(A,b,tol,maxit,M)
bicgstab(A,b,tol,maxit,M1,M2)
bicgstab(A,b,tol,maxit,M1,M2,x0)
bicgstab(afun,b,tol,maxit,m1fun,m2fun,x0,p1,p2,...)
[x,flag] = bicgstab(A,b,...)
[x,flag,relres] = bicgstab(A,b,...)
[x,flag,relres,iter] = bicgstab(A,b,...)
[x,flag,relres,iter,resvec] = bicgstab(A,b,...)
```

Description

`x = bicgstab(A,b)` attempts to solve the system of linear equations `A*x=b` for `x`. The `n`-by-`n` coefficient matrix `A` must be square and should be large and sparse. The column vector `b` must have length `n`. `A` can be a function `afun` such that `afun(x)` returns `A*x`.

If `bicgstab` converges, a message to that effect is displayed. If `bicgstab` fails to converge after the maximum number of iterations or halts for any reason, a warning message is printed displaying the relative residual `norm(b-A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`bicgstab(A,b,tol)` specifies the tolerance of the method. If `tol` is `[]`, then `bicgstab` uses the default, `1e-6`.

`bicgstab(A,b,tol,maxit)` specifies the maximum number of iterations. If `maxit` is `[]`, then `bicgstab` uses the default, `min(n,20)`.

`bicgstab(A,b,tol,maxit,M)` and `bicgstab(A,b,tol,maxit,M1,M2)` use preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. If `M` is `[]` then `bicgstab` applies no preconditioner. `M` can be a function `that` returns `M\x`.

`bicgstab(A,b,tol,maxit,M1,M2,x0)` specifies the initial guess. If `x0` is `[]`, then `bicgstab` uses the default, an all zero vector.

`bicgstab(afun,b,tol,maxit,m1fun,m2fun,x0,p1,p2,...)` passes parameters `p1,p2,...` to functions `afun(x,p1,p2,...)`, `m1fun(x,p1,p2,...)`, and `m2fun(x,p1,p2,...)`.

`[x,flag] = bicgstab(A,b,...)` also returns a convergence flag.

Flag	Convergence
0	`bicgstab` converged to the desired tolerance `tol` within `maxit` iterations.
1	`bicgstab` iterated `maxit` times but did not converge.
2	Preconditioner `M` was ill-conditioned.
3	`bicgstab` stagnated. (Two consecutive iterates were the same.)
4	One of the scalar quantities calculated during `bicgstab` became too small or too large to continue computing.

Whenever `flag` is not `0`, the solution `x` returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the `flag` output is specified.

`[x,flag,relres] = bicgstab(A,b,...)` also returns the relative residual `norm(b-A*x)/norm(b)`. If `flag` is `0`, `relres <= tol`.

`[x,flag,relres,iter] = bicgstab(A,b,...)` also returns the iteration number at which `x` was computed, where `0 <= iter <= maxit`. `iter` can be an integer + 0.5, indicating convergence half way through an iteration.

`[x,flag,relres,iter,resvec] = bicgstab(A,b,...)` also returns a vector of the residual norms at each half iteration, including `norm(b-A*x0)`.

Example

Example 1. This example first solves `Ax = b` by providing `A` and the preconditioner `M1` directly as arguments. It then solves the same system using functions that return `A` and the preconditioner.

```
A = gallery('wilk',21);
b = sum(A,2);
```

```
tol = 1e-12;
maxit = 15;
M1 = diag([10:-1:1 1 1:10]);

x = bicgstab(A,b,tol,maxit,M1,[],[]);
```

displays this message

```
bicgstab converged at iteration 12.5 to a solution with relative
residual 2.9e-014
```

Alternatively, use this matrix-vector product function

```
function y = afun(x,n)
y = [0;
     x(1:n-1)] + [((n-1)/2:-1:0)';
     (1:(n-1)/2)'] .*x + [x(2:n);
     0];
```

and this preconditioner backsolve function

```
function y = mfun(r,n)
y = r ./ [((n-1)/2:-1:1)'; 1; (1:(n-1)/2)'];
```

as inputs to `bicgstab`

```
x1 = bicgstab(@afun,b,tol,maxit,@mfun,[],[],21);
```

Note that both `afun` and `mfun` must accept `bicgstab`'s extra input `n=21`.

Example 2. This examples demonstrates the use of a preconditioner. Start with `A = west0479`, a real 479-by-479 sparse matrix, and define `b` so that the true solution is a vector of all ones.

```
load west0479;
A = west0479;
b = sum(A,2);
[x,flag] = bicgstab(A,b)
```

`flag` is `1` because `bicgstab` does not converge to the default tolerance `1e-6` within the default 20 iterations.

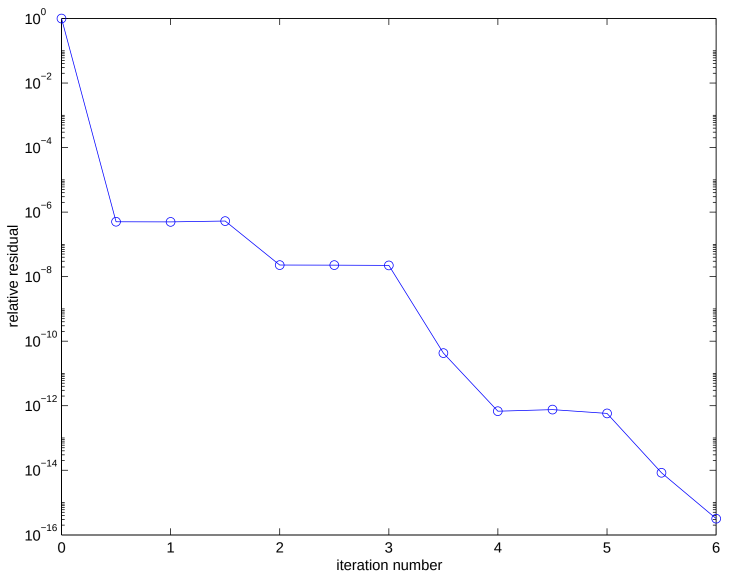
```
[L1,U1] = luinc(A,1e-5);
[x1,flag1] = bicgstab(A,b,1e-6,20,L1,U1)
```

flag1 is 2 because the upper triangular U1 has a zero on its diagonal. This causes bicgstab to fail in the first iteration when it tries to solve a system such as U1*y = r using backslash.

```
[L2,U2] = luinc(A,1e-6);
[x2,flag2,relres2,iter2,resvec2] = bicgstab(A,b,1e-15,10,L2,U2)
```

flag2 is 0 because bicgstab converges to the tolerance of 3.1757e-016 (the value of relres2) at the sixth iteration (the value of iter2) when preconditioned by the incomplete LU factorization with a drop tolerance of 1e-6. resvec2(1) = norm(b) and resvec2(13) = norm(b-A*x2). You can follow the progress of bicgstab by plotting the relative residuals at the halfway point and end of each iteration starting from the initial estimate (iterate number 0).

```
semilogy(0:0.5:iter2,resvec2/norm(b),'-o')
xlabel('iteration number')
ylabel('relative residual')
```



See Also

`bicg`, `cgs`, `gmres`, `lsqr`, `luinc`, `minres`, `pcg`, `qmr`, `symmlq`

`@` (function handle), `\` (backslash)

References

[1] Barrett, R., M. Berry, T. F. Chan, et al., *Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods*, SIAM, Philadelphia, 1994.

[2] van der Vorst, H. A., "BI-CGSTAB: A fast and smoothly converging variant of BI-CG for the solution of nonsymmetric linear systems", *SIAM J. Sci. Stat. Comput.*, March 1992,Vol. 13, No. 2, pp. 631-644.

Purpose Binary to decimal number conversion

Syntax `bin2dec(`*`binarystr`*`)`

Description `bin2dec(`*`binarystr`*`)` interprets the binary string *`binarystr`* and returns the equivalent decimal number.

Examples `bin2dec('010111')` returns 23.

See Also `dec2bin`

bitand

Purpose Bit-wise AND

Syntax

```
C = bitand(A,B)
```

Description `C = bitand(A,B)` returns the bit-wise AND of two nonnegative integer arguments `A` and `B`. To ensure the operands are integers, use the `ceil`, `fix`, `floor`, and `round` functions.

Examples The five-bit binary representations of the integers 13 and 27 are 01101 and 11011, respectively. Performing a bit-wise AND on these numbers yields 01001, or 9.

```
C = bitand(13,27)

C =

     9
```

See Also `bitcmp`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitshift`, `bitxor`

Purpose Complement bits

Syntax `C = bitcmp(A,n)`

Description `C = bitcmp(A,n)` returns the bit-wise complement of `A` as an `n`-bit floating-point integer (flint).

Example With eight-bit arithmetic, the ones' complement of 01100011 (99, decimal) is 10011100 (156, decimal).

```
C = bitcmp(99,8)

C =

   156
```

See Also `bitand`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitshift`, `bitxor`

bitget

Purpose Get bit

Syntax

```
C = bitget(A,bit)
```

Description `C = bitget(A,`*`bit`*`)` returns the value of the bit at position *`bit`* in `A`. Operand `A` must be a nonnegative integer, and *`bit`* must be a number between 1 and the number of bits in the floating-point integer (flint) representation of `A` (52 for IEEE flints). To ensure the operand is an integer, use the `ceil`, `fix`, `floor`, and `round` functions.

Example The `dec2bin` function converts decimal numbers to binary. However, you can also use the `bitget` function to show the binary representation of a decimal number. Just test successive bits from most to least significant:

```
disp(dec2bin(13))
1101
C = bitget(13,4:-1:1)

C =
     1     1     0     1
```

See Also `bitand`, `bitcmp`, `bitmax`, `bitor`, `bitset`, `bitshift`, `bitxor`

Purpose Maximum floating-point integer

Syntax `bitmax`

Description `bitmax` returns the maximum unsigned floating-point integer for your computer. It is the value when all bits are set, namely the value $2^{53} - 1$.

See Also `bitand`, `bitcmp`, `bitget`, `bitor`, `bitset`, `bitshift`, `bitxor`

bitor

Purpose Bit-wise OR

Syntax

```
C = bitor(A,B)
```

Description `C = bitor(A,B)` returns the bit-wise OR of two nonnegative integer arguments `A` and `B`. To ensure the operands are integers, use the `ceil`, `fix`, `floor`, and `round` functions.

Examples The five-bit binary representations of the integers 13 and 27 are 01101 and 11011, respectively. Performing a bit-wise OR on these numbers yields 11111, or 31.

```
C = bitor(13,27)

C =

    31
```

See Also `bitand`, `bitcmp`, `bitget`, `bitmax`, `bitset`, `bitshift`, `bitxor`

Purpose Set bit

Syntax

```
C = bitset(A,bit)
C = bitset(A,bit,v)
```

Description

`C = bitset(A,`*`bit`*`)` sets bit position *`bit`* in `A` to 1 (on). `A` must be a nonnegative integer and *`bit`* must be a number between 1 and the number of bits in the floating-point integer (flint) representation of `A` (52 for IEEE flints). To ensure the operand is an integer, use the `ceil`, `fix`, `floor`, and `round` functions.

`C = bitset(A,`*`bit`*`,v)` sets the bit at position *`bit`* to the value `v`, which must be either 0 or 1.

Examples

Setting the fifth bit in the five-bit binary representation of the integer 9 (01001) yields 11001, or 25.

```
C = bitset(9,5)

C =

    25
```

See Also

`bitand`, `bitcmp`, `bitget`, `bitmax`, `bitor`, `bitshift`, `bitxor`

bitshift

Purpose Bit-wise shift

Syntax

```
C = bitshift(A,k,n)
C = bitshift(A,k)
```

Description `C = bitshift(A,k,n)` returns the value of `A` shifted by `k` bits. If `k>0`, this is same as a multiplication by 2^k (left shift). If `k<0`, this is the same as a division by 2^k (right shift). An equivalent computation for this function is
`C = fix(A*2^k)`.

If the shift causes `C` to overflow `n` bits, the overflowing bits are dropped. `A` must contain nonnegative integers between `0` and `BITMAX`, which you can ensure by using the `ceil`, `fix`, `floor`, and `round` functions.

`C = bitshift(A,k)` uses the default value of `n = 53`.

Examples Shifting 1100 (12, decimal) to the left two bits yields 110000 (48, decimal).

```
C = bitshift(12,2)

C =

    48
```

See Also `bitand`, `bitcmp`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitxor`, `fix`

Purpose Bit-wise XOR

Syntax

```
C = bitxor(A,B)
```

Description `C = bitxor(A,B)` returns the bit-wise XOR of the two arguments `A` and `B`. Both `A` and `B` must be integers. You can ensure this by using the `ceil`, `fix`, `floor`, and `round` functions.

Examples The five-bit binary representations of the integers 13 and 27 are 01101 and 11011, respectively. Performing a bit-wise XOR on these numbers yields 10110, or 22.

```
C = bitxor(13,27)

C =
    22
```

See Also `bitand`, `bitcmp`, `bitget`, `bitmax`, `bitor`, `bitset`, `bitshift`

blanks

Purpose A string of blanks

Syntax

```
blanks(n)
```

Description

`blanks(n)` is a string of `n` blanks.

Examples

`blanks` is useful with the `display` function. For example,

```
disp(['xxx' blanks(20) 'yyy'])
```

displays twenty blanks between the strings `'xxx'` and `'yyy'`.

`disp(blanks(n)')` moves the cursor down `n` lines.

See Also

`clc`, `format`, `home`

Purpose Construct a block diagonal matrix from input arguments

Syntax

```
out = blkdiag(a,b,c,d,...)
```

Description `out = blkdiag(a,b,c,d,...)`, where `a`, `b`, `c`, `d`, ... are matrices, outputs a block diagonal matrix of the form

$$\begin{bmatrix} a & 0 & 0 & 0 & 0 \\ 0 & b & 0 & 0 & 0 \\ 0 & 0 & c & 0 & 0 \\ 0 & 0 & 0 & d & 0 \\ 0 & 0 & 0 & 0 & \ldots \end{bmatrix}$$

The input matrices do not have to be square, nor do they have to be of equal size.

Note `blkdiag` works not only for matrices, but for any MATLAB objects that support `horzcat` and `vertcat` operations.

See Also `diag`, `horzcat`, `vertcat`

box

Purpose

Display axes border

Syntax

```
box on
box off
box
box(axes_handle,...)
```

Description

`box on` displays the boundary of the current axes.

`box off` does not display the boundary of the current axes.

`box` toggles the visible state of the current axes' boundary.

`box(axes_handle,...)` uses the axes specified by `axes_handle` instead of the current axes.

Algorithm

The `box` function sets the axes `Box` property to `on` or `off`.

See Also

`axes`, `grid`

"Axes Operations" for related functions

Purpose Terminate execution of a `for` loop or `while` loop

Syntax

```
break
```

Description `break` terminates the execution of a `for` or `while` loop. Statements in the loop that appear after the `break` statement, are not executed.

In nested loops, `break` exits only from the loop in which it occurs. Control passes to the statement that follows the `end` of that loop.

Remarks `break` is not defined outside of a `for` or `while` loop. Use `return` in this context instead.

Examples The example below shows a `while` loop that reads the contents of the file `fft.m` into a MATLAB character array. A `break` statement is used to exit the `while` loop when the first empty line is encountered. The resulting character array contains the M-file help for the `fft` program.

```
fid = fopen('fft.m','r');
s = '';
while ~feof(fid)
   line = fgetl(fid);
   if isempty(line), break, end
   s = strvcat(s,line);
end
disp(s)
```

See Also `for`, `while`, `end`, `continue`, `return`

Purpose Brighten or darken colormap

Syntax

```
brighten(beta)
brighten(h,beta)
newmap = brighten(beta)
newmap = brighten(cmap,beta)
```

Description `brighten` increases or decreases the color intensities in a colormap. The modified colormap is brighter if `0 < beta < 1` and darker if `–1 < beta < 0`.

`brighten(beta)` replaces the current colormap with a brighter or darker colormap of essentially the same colors. `brighten(beta)`, followed by `brighten(–beta)`, where `beta < 1`, restores the original map.

`brighten(h,beta)` brightens all objects that are children of the figure having the handle `h`.

`newmap = brighten(beta)` returns a brighter or darker version of the current colormap without changing the display.

`newmap = brighten(cmap,beta)` returns a brighter or darker version of the colormap `cmap` without changing the display.

Examples Brighten and then darken the current colormap:

```
beta = .5; brighten(beta);
beta = –.5; brighten(beta);
```

Algorithm The values in the colormap are raised to the power of gamma, where gamma is

$$\gamma = \begin{cases} 1 - \beta, & \beta > 0 \\ \dfrac{1}{1 + \beta}, & \beta \le 0 \end{cases}$$

`brighten` has no effect on graphics objects defined with true color.

See Also `colormap`, `rgbplot`

"Color Operations" for related functions

Altering Colormaps for more information

builtin

Purpose Execute builtin function from overloaded method

Syntax

```
builtin(function,x1,...,xn)
[y1,..,yn] = builtin(function,x1,...,xn)
```

Description `builtin` is used in methods that overload builtin functions to execute the original builtin function. If *`function`* is a string containing the name of a builtin function, then

`builtin(`*`function`*`,x1,...,xn)` evaluates that function at the given arguments.

`[y1,..,yn] = builtin(`*`function`*`,x1,...,xn)` returns multiple output arguments.

Remarks `builtin`(...) is the same as `feval`(...) except that it calls the original builtin version of the function even if an overloaded one exists. (For this to work you must never overload `builtin`.)

See Also `feval`

Purpose

Solve two-point boundary value problems (BVPs) for ordinary differential equations

Syntax

```
sol = bvp4c(odefun,bcfun,solinit)
sol = bvp4c(odefun,bcfun,solinit,options)
sol = bvp4c(odefun,bcfun,solinit,options,p1,p2...)
```

Arguments

`odefun` A function that evaluates the differential equations $f(x, y)$. It can have the form

```
dydx = odefun(x,y)
dydx = odefun(x,y,p1,p2,...)
dydx = odefun(x,y,parameters)
dydx = odefun(x,y,parameters,p1,p2,...)
```

where `x` is a scalar corresponding to x, and `y` is a column vector corresponding to y. `parameters` is a vector of unknown parameters, and `p1,p2,...` are known parameters. The output `dydx` is a column vector.

`bcfun` A function that computes the residual in the boundary conditions $bc(y(a), y(b))$. It can have the form

```
res = bcfun(ya,yb)
res = bcfun(ya,yb,p1,p2,...)
res = bcfun(ya,yb,parameters)
res = bcfun(ya,yb,parameters,p1,p2,...)
```

where `ya` and `yb` are column vectors corresponding to $y(a)$ and $y(b)$. `parameters` is a vector of unknown parameters, and `p1,p2,...` are known parameters. The output `res` is a column vector.

`solinit` A structure with fields:

`x`	Ordered nodes of the initial mesh. Boundary conditions are imposed at a = `solinit.x(1)` and b = `solinit.x(end)`.
`y`	Initial guess for the solution such that `solinit.y(:,i)` is a guess for the solution at the node `solinit.x(i)`.

`parameters`	Optional. A vector that provides an initial guess for unknown parameters.

The structure can have any name, but the fields must be named `x`, `y`, and `parameters`. You can form `solinit` with the helper function `bvpinit`. See `bvpinit` for details.

`options`	Optional integration argument. A structure you create using the `bvpset` function. See `bvpset` for details.
`p1,p2...`	Optional. Known parameters that the solver passes to `odefun`, `bcfun`, and all the functions specified in `options`.

Description

`sol = bvp4c(odefun,bcfun,solinit)` integrates a system of ordinary differential equations of the form

$$y' = f(x, y)$$

on the interval [a,b] subject to general two-point boundary conditions

$$bc(y(a), y(b)) = 0$$

The `bvp4c` solver can also find unknown parameters p for problems of the form

$$y' = f(x, y, p)$$
$$bc(y(a), y(b), p) = 0$$

where p corresponds to `parameters`. You provide `bvp4c` an initial guess for any unknown parameters in `solinit.parameters`. The `bvp4c` solver returns the final values of these unknown parameters in `sol.parameters`.

`bvp4c` produces a solution that is continuous on [a,b] and has a continuous first derivative there. Use the function `deval` and the output `sol` of `bvp4c` to evaluate the solution at specific points `xint` in the interval [a,b].

```
sxint = deval(sol,xint)
```

The structure `sol` returned by `bvp4c` has the following fields:

`sol.x`	Mesh selected by `bvp4c`
`sol.y`	Approximation to $y(x)$ at the mesh points of `sol.x`
`sol.yp`	Approximation to $y'(x)$ at the mesh points of `sol.x`

`sol.parameters`	Values returned by `bvp4c` for the unknown parameters, if any
`sol.solver`	'bvp4c'

The structure `sol` can have any name, and `bvp4c` creates the fields `x`, `y`, `yp`, `parameters`, and `solver`.

`sol = bvp4c(odefun,bcfun,solinit,options)` solves as above with default integration properties replaced by the values in `options`, a structure created with the `bvpset` function. See `bvpset` for details.

`sol = bvp4c(odefun,bcfun,solinit,options,p1,p2...)` passes constant *known* parameters, `p1`, `p2`, ..., to `odefun`, `bcfun`, and all the functions the user specifies in `options`. Use `options = []` as a placeholder if no options are set.

Examples

Example 1. Boundary value problems can have multiple solutions and one purpose of the initial guess is to indicate which solution you want. The second order differential equation

$$y'' + |y| = 0$$

has exactly two solutions that satisfy the boundary conditions

$$y(0) = 0$$
$$y(4) = -2$$

Prior to solving this problem with `bvp4c`, you must write the differential equation as a system of two first order ODEs

$$y_1' = y_2$$
$$y_2' = -|y_1|$$

Here $y_1 = y$ and $y_2 = y'$. This system has the required form

$$y' = f(x, y)$$
$$bc(y(a), y(b)) = 0$$

The function f and the boundary conditions bc are coded in MATLAB as functions `twoode` and `twobc`.

```
function dydx = twoode(x,y)
  dydx = [ y(2)
           -abs(y(1))];

function res = twobc(ya,yb)
  res = [ ya(1)
          yb(1) + 2];
```

Form a guess structure consisting of an initial mesh of five equally spaced points in [0,4] and a guess of constant values $y_1(x) \equiv 1$ and $y_2(x) \equiv 0$ with the command

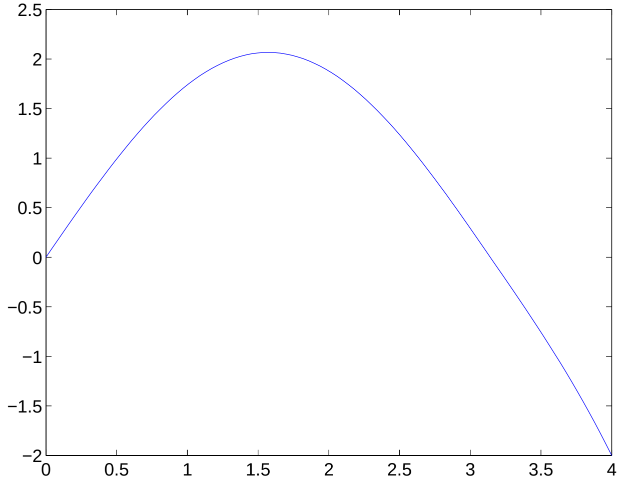
```
solinit = bvpinit(linspace(0,4,5),[1 0]);
```

Now solve the problem with

```
sol = bvp4c(@twoode,@twobc,solinit);
```

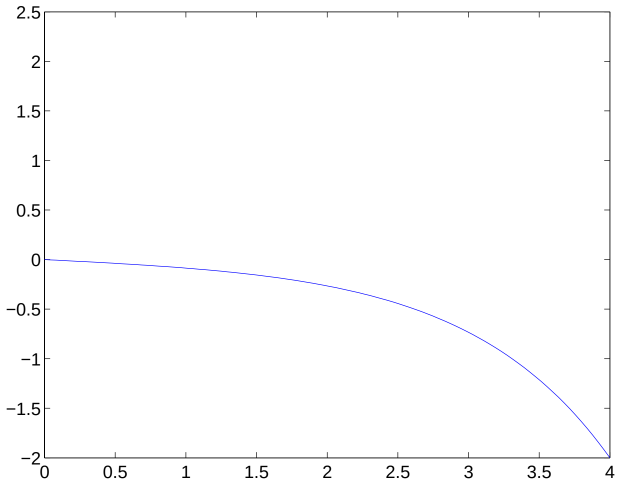
Evaluate the numerical solution at 100 equally spaced points and plot $y(x)$ with

```
x = linspace(0,4);
y = deval(sol,x);
plot(x,y(1,:));
```



You can obtain the other solution of this problem with the initial guess

```
solinit = bvpinit(linspace(0,4,5),[-1 0]);
```



Example 2. This boundary value problem involves an unknown parameter. The task is to compute the fourth ($q = 5$) eigenvalue λ of Mathieu's equation

$$y'' + (\lambda - 2q\cos 2x)y = 0$$

Because the unknown parameter λ is present, this second order differential equation is subject to *three* boundary conditions

$$y'(0) = 0$$
$$y'(\pi) = 0$$
$$y(0) = 1$$

It is convenient to use subfunctions to place all the functions required by bvp4c in a single M-file.

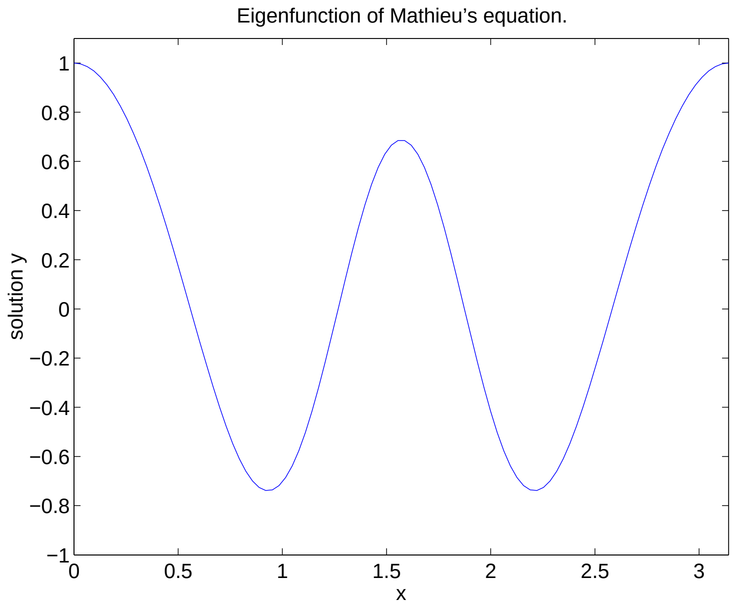
```
function mat4bvp

lambda = 15;
solinit = bvpinit(linspace(0,pi,10),@mat4init,lambda);
sol = bvp4c(@mat4ode,@mat4bc,solinit);
```

```
fprintf('The fourth eigenvalue is approximately %7.3f.\n',...
        sol.parameters)

xint = linspace(0,pi);
Sxint = deval(sol,xint);
plot(xint,Sxint(1,:))
axis([0 pi -1 1.1])
title('Eigenfunction of Mathieu''s equation.')
xlabel('x')
ylabel('solution y')
% ------------------------------------------------------------
function dydx = mat4ode(x,y,lambda)
q = 5;
dydx = [  y(2)
         -(lambda - 2*q*cos(2*x))*y(1) ];
% ------------------------------------------------------------
function res = mat4bc(ya,yb,lambda)
res = [  ya(2)
         yb(2)
        ya(1)-1 ];
% ------------------------------------------------------------
function yinit = mat4init(x)
yinit = [  cos(4*x)
          -4*sin(4*x) ];
```

The differential equation (converted to a first order system) and the boundary conditions are coded as subfunctions `mat4ode` and `mat4bc`, respectively. Because unknown parameters are present, these functions must accept three input arguments, even though some of the arguments are not used.

The guess structure `solinit` is formed with `bvpinit`. An initial guess for the solution is supplied in the form of a function `mat4init`. We chose $y = \cos 4x$ because it satisfies the boundary conditions and has the correct qualitative behavior (the correct number of sign changes). In the call to `bvpinit`, the third argument (`lambda = 15`) provides an initial guess for the unknown parameter λ.

After the problem is solved with bvp4c, the field sol.parameters returns the value $\lambda = 17.097$, and the plot shows the eigenfunction associated with this eigenvalue.



Algorithms

bvp4c is a finite difference code that implements the three-stage Lobatto IIIa formula. This is a collocation formula and the collocation polynomial provides a C^1-continuous solution that is fourth order accurate uniformly in [a,b]. Mesh selection and error control are based on the residual of the continuous solution.

See Also

@ (function_handle), bvpget, bvpinit, bvpset, deval

References

[1] Shampine, L.F., M.W. Reichelt, and J. Kierzenka, "Solving Boundary Value Problems for Ordinary Differential Equations in MATLAB with bvp4c," available at ftp://ftp.mathworks.com/pub/doc/papers/bvp/.

bvpget

Purpose Extract properties from the options structure created with bvpset

Syntax

```
val = bvpget(options,'name')
val = bvpget(options,'name',default)
```

Description `val = bvpget(options,'name')` extracts the value of the named property from the structure `options`, returning an empty matrix if the property value is not specified in `options`. It is sufficient to type only the leading characters that uniquely identify the property. Case is ignored for property names. `[]` is a valid `options` argument.

`val = bvpget(options,'name',default)` extracts the named property as above, but returns `val = default` if the named property is not specified in `options`. For example,

```
val = bvpget(opts,'RelTol',1e-4);
```

returns `val = 1e-4` if the `RelTol` is not specified in `opts`.

See Also `bvp4c`, `bvpinit`, `bvpset`, `deval`

Purpose

Form the initial guess for bvp4c

Syntax

```
solinit = bvpinit(x,v)
solinit = bvpinit(x,v,parameters)
solinit = bvpinit(sol,[anew bnew])
solinit = bvpinit(sol,[anew bnew],parameters)
```

Description

`solinit = bvpinit(x,v)` forms the initial guess for `bvp4c` in common circumstances.

`x` is a vector that specifies an initial mesh. If you want to solve the boundary value problem (BVP) on $[a, b]$, then specify `x(1)` as a and `x(end)` as b. The function `bvp4c` adapts this mesh to the solution, so often a guess like `x = linspace(a,b,10)` suffices. However, in difficult cases, you must place mesh points where the solution changes rapidly. The entries of `x` must be ordered and distinct, so if $a < b$, then `x(1) < x(2) < ... < x(end)`, and similarly for $a > b$.

`v` is a guess for the solution. It can be either a vector, or a function:

- Vector – For each component of the solution, `bvpinit` replicates the corresponding element of the vector as a constant guess across all mesh points. That is, `v(i)` is a constant guess for the `i`th component `y(i,:)` of the solution at all the mesh points in `x`.
- Function – For a given mesh point, the function must return a vector whose elements are guesses for the corresponding components of the solution. The function must be of the form

  ```
  y = guess(x)
  ```

  where `x` is a mesh point and `y` is a vector whose length is the same as the number of components in the solution. For example, if you use `@guess`, `bvpinit` calls this function for each mesh point `y(:,j) = guess(x(j))`.

`solinit = bvpinit(x,v,parameters)` indicates that the BVP involves unknown parameters. Use the vector `parameters` to provide a guess for all unknown parameters.

`solinit` is a structure with the following fields. The structure can have any name, but the fields must be named `x`, `y`, and `parameters`.

`x`	Ordered nodes of the initial mesh.
`y`	Initial guess for the solution with `solinit.y(:,i)` a guess for the solution at the node `solinit.x(i)`.
`parameters`	Optional. A vector that provides an initial guess for unknown parameters.

`solinit = bvpinit(sol,[anew bnew])` forms an initial guess on the interval `[anew bnew]` from a solution `sol` on an interval $[a, b]$. The new interval must be larger than the previous one, so either `anew <=` a `<` b `<= bnew` or `anew >=` a `>` b `>= bnew`. The solution `sol` is extrapolated to the new interval. If `sol` contains `parameters`, they are copied to `solinit`.

`solinit = bvpinit(sol,[anew bnew],parameters)` forms `solinit` as described above, but uses `parameters` as a guess for unknown parameters in `solinit`.

See Also

`@` `(function_handle)`, `bvp4c`, `bvpget`, `bvpset`, `deval`

Purpose

Create/alter boundary value problem (BVP) options structure

Syntax

```
options = bvpset('name1',value1,'name2',value2,...)
options = bvpset(oldopts'name1',value1,...)
options = bvpset(oldopts,newopts)
bvpset
```

Description

`options = bvpset('name1',value1,'name2',value2,...)` creates a structure `options` in which the named properties have the specified values. Any unspecified properties have default values. It is sufficient to type only the leading characters that uniquely identify the property. Case is ignored for property names.

`options = bvpset(oldopts,'name1',value1,...)` alters an existing options structure `oldopts`.

`options = bvpset(oldopts,newopts)` combines an existing options structure `oldopts` with a new options structure `newopts`. Any new properties overwrite corresponding old properties.

`bvpset` with no input arguments displays all property names and their possible values.

BVP Properties

These properties are available.

Property	Value	Description
`RelTol`	Positive scalar {`1e-3`}	A relative tolerance that applies to all components of the residual vector. The computed solution $S(x)$ is the exact solution of $S'(x) = F(x, S(x)) + \mathrm{res}(x)$. On each subinterval of the mesh, the residual $\mathrm{res}(x)$ satisfies $\lVert(\mathrm{res(i)/max(abs(F(i)),AbsTol(i)/RelTol)})\rVert \le \mathrm{RelTol}$
`AbsTol`	Positive scalar or vector {`1e-6`}	An absolue tolerance that applies to all components of the residual vector. Elements of a vector of tolerances apply to corresponding components of the residual vector.

Property	Value	Description
`Vectorized`	`on` | {`off`}	Set `on` to inform `bvp4c` that you have coded the ODE function `F` so that `F([x1 x2 ...],[y1 y2 ...])` returns `[F(x1,y1) F(x2,y2) ...]`. That is, your ODE function can pass to the solver a whole array of column vectors at once. This allows the solver to reduce the number of function evaluations, and may significantly reduce solution time.
`SingularTerm`	Matrix	Singular term of singular BVPs. Set to the constant matrix `S` for equations of the form $y' = S\frac{y}{x} + f(x, y, p)$ that are posed on the interval $[0, b]$ where $b > 0$.
`FJacobian`	Function | matrix | cell array	Analytic partial derivatives of `ODEFUN`. For example, when solving $y' = f(x, y)$, set this property to `@FJAC` if `DFDY = FJAC(X,Y)` evaluates the Jacobian of f with respect to y. If the problem involves unknown parameters p, `[DFDY,DFDP] = FJAC(X,Y,P)` must also return the partial derivative of f with respect to p. For problems with constant partial derivatives, set this property to the value of `DFDY` or to a cell array `{DFDY,DFDP}`.
`BCJacobian`	Function | cell array	Analytic partial derivatives of `BCFUN`. For example, for boundary conditions $bc(ya, yb) = 0$, set this property to `@BCJAC` if `[DBCDYA,DBCDYB] = BCJAC(YA,YB)` evaluates the partial derivatives of bc with respect to ya and to yb. If the problem involves unknown parameters p, then `[DBCDYA,DBCDYB,DBCDP] = BCJAC(YA,YB,P)` must also return the partial derivative of bc with respect to p. For problems with constant partial derivatives, set this property to a cell array `{DBCDYA,DBCDYB}` or `{DBCDYA,DBCDYB,DBCDP}`.

Property	Value	Description
`Nmax`	positive integer {`floor(1000/n)`}	Maximum number of mesh points allowed.
`Stats`	`on` | {`off`}	Display computational cost statistics.

See Also `@` (`function_handle`), `bvp4c`, `bvpget`, `bvpinit`, `deval`

bvpval

Purpose

Evaluate the numerical solution of a boundary value problem (BVP) using the output of `bvp4c`

Note `bvpval` is obsolete and will be removed in the future. Please use `deval` instead.

Syntax

```
sxint = bvpval(sol,xint)
```

Description

`sxint = bvpval(sol,xint)` uses `sol`, the output of `bvp4c`, to evaluate the solution of a boundary value problem at each element of the vector `xint`. For each `i`, `sxint(:,i)` is the solution corresponding to `xint(i)`.

See Also

`bvp4c`, `bvpinit`, `bvpget`, `bvpset`

Purpose

Calendar

Syntax

```
c = calendar
c = calendar(d)
c = calendar(y,m)

calendar(...)
```

Description

`c = calendar` returns a 6-by-7 matrix containing a calendar for the current month. The calendar runs Sunday (first column) to Saturday.

`c = calendar(d)`, where `d` is a serial date number or a date string, returns a calendar for the specified month.

`c = calendar(y,m)`, where `y` and `m` are integers, returns a calendar for the specified month of the specified year.

`calendar(...)` displays the calendar on the screen.

Examples

The command:

```
calendar(1957,10)
```

reveals that the Space Age began on a Friday (on October 4, 1957, when Sputnik 1 was launched).

```
                    Oct 1957
     S     M    Tu     W    Th     F     S
     0     0     1     2     3     4     5
     6     7     8     9    10    11    12
    13    14    15    16    17    18    19
    20    21    22    23    24    25    26
    27    28    29    30    31     0     0
     0     0     0     0     0     0     0
```

See Also

`datenum`

camdolly

Purpose Move the camera position and target

Syntax

```
camdolly(dx,dy,dz)
camdolly(dx,dy,dz,'targetmode')
camdolly(dx,dy,dz,'targetmode','coordsys')
camdolly(axes_handle,...)
```

Description

`camdolly` moves the camera position and the camera target by the specified amounts.

`camdolly(dx,dy,dz)` moves the camera position and the camera target by the specified amounts (see “Coordinate Systems”).

`camdolly(dx,dy,dz,'`*`targetmode`*`')` The *`targetmode`* argument can take on two values that determine how MATLAB moves the camera:

- `movetarget` (default) – move both the camera and the target
- `fixtarget` – move only the camera

`camdolly(dx,dy,dz,'`*`targetmode`*`','`*`coordsys`*`')` The *`coordsys`* argument can take on three values that determine how MATLAB interprets `dx`, `dy`, and `dz`:

Coordinate Systems

- `camera` (default) – move in the camera’s coordinate system. `dx` moves left/right, `dy` moves down/up, and `dz` moves along the viewing axis. The units are normalized to the scene.

  For example, setting `dx` to 1 moves the camera to the right, which pushes the scene to the left edge of the box formed by the axes position rectangle. A negative value moves the scene in the other direction. Setting `dz` to 0.5 moves the camera to a position halfway between the camera position and the camera target
- `pixels` – interpret `dx` and `dy` as pixel offsets. `dz` is ignored.
- `data` – interpret `dx`, `dy`, and `dz` as offesets in axes data coordinates.

`camdolly(axes_handle,...)` operates on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `camdolly` operates on the current axes.

Remarks

camdolly sets the axes CameraPosition and CameraTarget properties, which in turn causes the CameraPositionMode and CameraTargetMode properties to be set to manual.

Examples

This example moves the camera along the *x*- and *y*-axes in a series of steps.

```
surf(peaks)
axis vis3d
t = 0:pi/20:2*pi;
dx = sin(t)./40;
dy = cos(t)./40;
for i = 1:length(t);
    camdolly(dx(i),dy(i),0)
    drawnow
end
```

See Also

axes, campos, camproj, camtarget, camup, camva

The axes properties CameraPosition, CameraTarget, CameraUpVector, CameraViewAngle, Projection

"Controlling the Camera Viewpoint" for related functions

See Defining Scenes with Camera Graphics for more information on camera properties.

camlight

Purpose Create or move a light object in camera coordinates

Syntax

```
camlight headlight
camlight right
camlight left
camlight
camlight(az,el)
camlight(...‘style’)
camlight(light_handle,...)
light_handle = camlight(...)
```

Description

`camlight('headlight')` creates a light at the camera position.

`camlight('right')` creates a light right and up from camera.

`camlight('left')` creates a light left and up from camera.

`camlight` with no arguments is the same as `camlight('right')`.

`camlight(az,el)` creates a light at the specified azimuth (`az`) and elevation (`el`) with respect to the camera position. The camera target is the center of rotation and `az` and `el` are in degrees.

`camlight(...,'style')` The style argument can take on the two values:

- `local` (default) – the light is a point source that radiates from the location in all directions.
- `infinite` – the light shines in parallel rays.

`camlight(light_handle,...)` uses the light specified in `light_handle`.

`light_handle = camlight(...)` returns the light’s handle.

Remarks

`camlight` sets the light object `Position` and `Style` properties. A light created with `camlight` will not track the camera. In order for the light to stay in a constant position relative to the camera, you must call `camlight` whenever you move the camera.

Examples

This example creates a light positioned to the left of the camera and then repositions the light each time the camera is moved:

```
surf(peaks)
axis vis3d
h = camlight('left');
for i = 1:20;
   camorbit(10,0)
   camlight(h,'left')
   drawnow;
end
```

See Also

`light`, `lightangle`

"Lighting" for related functions

Lighting as a Visualization Tool for more information on using lights

Purpose

Position the camera to view an object or group of objects

Syntax

```
camlookat(object_handles)
camlookat(axes_handle)
camlookat
```

Description

`camlookat(object_handles)` views the objects identified in the vector `object_handles`. The vector can contain the handles of axes children.

`camlookat(axes_handle)` views the objects that are children of the axes identified by `axes_handle`.

`camlookat` views the objects that are in the current axes.

Remarks

`camlookat` moves the camera position and camera target while preserving the relative view direction and camera view angle. The object (or objects) being viewed roughly fill the axes position rectangle.

`camlookat` sets the axes `CameraPosition` and `CameraTarget` properties.

Examples

This example creates three spheres at different locations and then progressively positions the camera so that each sphere is the object around which the scene is composed:

```
[x y z] = sphere;
s1 = surf(x,y,z);
hold on
s2 = surf(x+3,y,z+3);
s3 = surf(x,y,z+6);
daspect([1 1 1])
view(30,10)
camproj perspective
camlookat(gca) % Compose the scene around the current axes
pause(2)
camlookat(s1)  % Compose the scene around sphere s1
pause(2)
camlookat(s2)  % Compose the scene around sphere s2
pause(2)
camlookat(s3)  % Compose the scene around sphere s3
pause(2)
camlookat(gca)
```

See Also

`campos`, `camtarget`

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

Purpose Rotate the camera position around the camera target

Syntax

```
camorbit(dtheta,dphi)
camorbit(dtheta,dphi,'coordsys')
camorbit(dtheta,dphi,'coordsys','direction')
camorbit(axes_handle,...)
```

Description

`camorbit(dtheta,dphi)` rotates the camera position around the camera target by the amounts specified in `dtheta` and `dphi` (both in degrees). `dtheta` is the horizontal rotation and `dphi` is the vertical rotation.

`camorbit(dtheta,dphi,'`*`coordsys`*`')` The *coordsys* argument determines the center of rotation. It can take on two values:

- `data` (default) – rotate the camera around an axis defined by the camera target and the `direction` (default is the positive z direction).
- `camera` – rotate the camera about the point defined by the camera target.

`camorbit(dtheta,dphi,'`*`coordsys`*`','direction')` The `direction` argument, in conjunction with the camera target, defines the axis of rotation for the data coordinate system. Specify `direction` as a three-element vector containing the x, y, and z-components of the direction or one of the characters, `x`, `y`, or `z`, to indicate `[1 0 0]`, `[0 1 0]`, or `[0 0 1]` respectively.

`camorbit(axes_handle,...)` operates on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `camorbit` operates on the current axes.

Examples

Compare rotation in the two coordinate systems with these `for` loops. The first rotates the camera horizontally about a line defined by the camera target point and a direction that is parallel to the *y*-axis. Visualize this rotation as a cone formed with the camera target at the apex and the camera position forming the base:

```
surf(peaks)
axis vis3d
for i=1:36
   camorbit(10,0,'data',[0 1 0])
   drawnow
```

```
end
```

Rotation in the `camera` coordinate system orbits the camera around the axes along a circle while keeping the center of a circle at the camera target.

```
surf(peaks)
axis vis3d
for i=1:36
   camorbit(10,0,'camera')
   drawnow
end
```

See Also

`axes`, `axis('vis3d')`, `camdolly`, `campan`, `camzoom`, `camroll`

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

campan

Purpose Rotate the camera target around the camera position

Syntax

```
campan(dtheta,dphi)
campan(dtheta,dphi,'coordsys')
campan(dtheta,dphi,'coordsys','direction')
campan(axes_handle,...)
```

Description `campan(dtheta,dphi)` rotates the camera target around the camera position by the amounts specified in `dtheta` and `dphi` (both in degrees). `dtheta` is the horizontal rotation and `dphi` is the vertical rotation.

`campan(dtheta,dphi,'`*`coordsys`*`')` The `coordsys` argument determines the center of rotation. It can take on two values:

- `data` (default) – rotate the camera target around an axis defined by the camera position and the `direction` (default is the positive z direction)
- `camera` – rotate the camera about the point defined by the camera target.

`campan(dtheta,dphi,'`*`coordsys`*`','direction')` The `direction` argument, in conjunction with the camera position, defines the axis of rotation for the data coordinate system. Specify `direction` as a three-element vector containing the x, y, and z-components of the direction or one of the characters, `x`, `y`, or `z`, to indicate `[1 0 0]`, `[0 1 0]`, or `[0 0 1]` respectively.

`campan(axes_handle,...)` operates on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `campan` operates on the current axes.

See Also `axes`, `camdolly`, `camorbit`, `camtarget`, `camzoom`, `camroll`

“Controlling the Camera Viewpoint” for related functions

Defining Scenes with Camera Graphics for more information

Purpose Set or query the camera position

Syntax

```
campos
campos([camera_position])
campos('mode')
campos('auto'
campos('manual')
campos(axes_handle,...)
```

Description `campos` with no arguments returns the camera position in the current axes.

`campos([camera_position])` sets the position of the camera in the current axes to the specified value. Specify the position as a three-element vector containing the x-, y-, and z-coordinates of the desired location in the data units of the axes.

`campos('mode')` returns the value of the camera position mode, which can be either `auto` (the default) or `manual`.

`campos('auto')` sets the camera position mode to `auto`.

`campos('manual')` sets the camera position mode to `manual`.

`campos(axes_handle,...)` performs the set or query on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `campos` operates on the current axes.

Remarks `campos` sets or queries values of the axes `CameraPosition` and `CameraPositionMode` properties. The camera position is the point in the Cartesian coordinate system of the axes from which you view the scene.

Examples This example moves the camera along the *x*-axis in a series of steps:

```
surf(peaks)
axis vis3d off
for x = –200:5:200
    campos([x,5,10])
    drawnow
end
```

See Also

`axis`, `camproj`, `camtarget`, `camup`, `camva`

The axes properties `CameraPosition`, `CameraTarget`, `CameraUpVector`, `CameraViewAngle`, `Projection`

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

Purpose Set or query the projection type

Syntax

```
camproj
camproj(projection_type)
camproj(axes_handle,...)
```

Description The projection type determines whether MATLAB uses a perspective or orthographic projection for 3-D views.

`camproj` with no arguments returns the projection type setting in the current axes.

`camproj('`*`projection_type`*`')` sets the projection type in the current axes to the specified value. Possible values for *`projection_type`* are: `orthographic` and `perspective`.

`camproj(axes_handle,...)` performs the set or query on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `camproj` operates on the current axes.

Remarks `camproj` sets or queries values of the axes object `Projection` property.

See Also `campos`, `camtarget`, `camup`, `camva`

The axes properties `CameraPosition`, `CameraTarget`, `CameraUpVector`, `CameraViewAngle`, `Projection`

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

Purpose

Rotate the camera about the view axis

Syntax

```
camroll(dtheta)
camroll(axes_handle,dtheta)
```

Description

`camroll(dtheta)` rotates the camera around the camera viewing axis by the amounts specified in `dtheta` (in degrees). The viewing axis is defined by the line passing through the camera position and the camera target.

`camroll(axes_handle,dtheta)` operates on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `camroll` operates on the current axes.

Remarks

`camroll` set the axes `CameraUpVector` property and thereby also sets the `CameraUpVectorMode` property to `manual`.

See Also

`axes`, `axis('vis3d')`, `camdolly`, `camorbit`, `camzoom`, `campan`

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

Purpose

Set or query the location of the camera target

Syntax

```
camtarget
camtarget([camera_target])
camtarget('mode')
camtarget('auto')
camtarget('manual')
camtarget(axes_handle,...)
```

Description

The camera target is the location in the axes that the camera points to. The camera remains oriented toward this point regardless of its position.

`camtarget` with no arguments returns the location of the camera target in the current axes.

`camtarget([camera_target])` sets the camera target in the current axes to the specified value. Specify the target as a three-element vector containing the x-, y-, and z-coordinates of the desired location in the data units of the axes.

`camtarget('mode')` returns the value of the camera target mode, which can be either `auto` (the default) or `manual`.

`camtarget('auto')` sets the camera target mode to `auto`.

`camtarget('manual')` sets the camera target mode to `manual`.

`camtarget(axes_handle,...)` performs the set or query on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `camtarget` operates on the current axes.

Remarks

`camtarget` sets or queries values of the axes object `Cameratarget` and `CameraTargetMode` properties.

When the camera target mode is `auto`, MATLAB positions the camera target at the center of the axes plot box.

Examples

This example moves the camera position and the camera target along the *x*-axis in a series of steps:

```
surf(peaks);
```

```
axis vis3d
xp = linspace(–150,40,50);
xt = linspace(25,50,50);
for i=1:50
     campos([xp(i),25,5]);
     camtarget([xt(i),30,0])
     drawnow
end
```

See Also

axis, camproj, campos, camup, camva

The axes properties CameraPosition, CameraTarget, CameraUpVector, CameraViewAngle, Projection

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

Purpose Set or query the camera up vector

Syntax

```
camup
camup([up_vector])
camup('mode')
camup('auto')
camup('manual')
camup(axes_handle,...)
```

Description The camera up vector specifies the direction that is oriented up in the scene.

`camup` with no arguments returns the camera up vector setting in the current axes.

`camup([up_vector])` sets the up vector in the current axes to the specified value. Specify the up vector as x-, y-, and z-components. See Remarks.

`camup('mode')` returns the current value of the camera up vector mode, which can be either `auto` (the default) or `manual`.

`camup('auto')` sets the camera up vector mode to `auto`. In `auto` mode, MATLAB uses a value for the up vector of `[0 1 0]` for 2-D views. This means the z-axis points up.

`camup('manual')` sets the camera up vector mode to `manual`. In `manual` mode, MATLAB does not change the value of the camera up vector.

`camup(axes_handle,...)` performs the set or query on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `camup` operates on the current axes.

Remarks `camup` sets or queries values of the axes object `CameraUpVector` and `CameraUpVectorMode` properties.

Specify the camera up vector as the x-, y-, and z-coordinates of a point in the axes coordinate system that forms the directed line segment PQ, where P is the point (0,0,0) and Q is the specified x-, y-, and z-coordinates. This line always points up. The length of the line PQ has no effect on the orientation of the scene. This means a value of `[0 0 1]` produces the same results as `[0 0 25]`.

See Also

`axis`, `camproj`, `campos`, `camtarget`, `camva`

The axes properties `CameraPosition`, `CameraTarget`, `CameraUpVector`, `CameraViewAngle`, `Projection`

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

Purpose Set or query the camera view angle

Syntax

```
camva
camva(view_angle)
camva('mode')
camva('auto')
camva('manual')
camva(axes_handle,...)
```

Description The camera view angle determines the field of view of the camera. Larger angles produce a smaller view of the scene. You can implement zooming by changing the camera view angle.

`camva` with no arguments returns the camera view angle setting in the current axes.

`camva(view_angle)` sets the view angle in the current axes to the specified value. Specify the view angle in degrees.

`camva('mode')` returns the current value of the camera view angle mode, which can be either `auto` (the default) or `manual`. See Remarks.

`camva('auto')` sets the camera view angle mode to `auto`.

`camva('manual')` sets the camera view angle mode to `manual`. See Remarks.

`camva(axes_handle,...)` performs the set or query on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `camva` operates on the current axes.

Remarks `camva` sets or queries values of the axes object `CameraViewAngle` and `CameraViewAngleMode` properties.

When the camera view angle mode is `auto`, MATLAB adjusts the camera view angle so that the scene fills the available space in the window. If you move the camera to a different position, MATLAB changes the camera view angle to maintain a view of the scene that fills the available area in the window.

Setting a camera view angle or setting the camera view angle to `manual` disables the MATLAB stretch-to-fill feature (stretching of the axes to fit the window). This means setting the camera view angle to its current value,

```
camva(camva)
```

can cause a change in the way the graph looks. See the Remarks section of the axes reference page for more information.

Examples

This example creates two pushbuttons, one that zooms in and another that zooms out.

```
uicontrol('Style','pushbutton',...
  'String','Zoom In',...
  'Position',[20 20 60 20],...
  'Callback','if camva <= 1;return;else;camva(camva-1);end');
uicontrol('Style','pushbutton',...
  'String','Zoom Out',...
  'Position',[100 20 60 20],...
  'Callback','if camva >= 179;return;else;camva(camva+1);end');
```

Now create a graph to zoom in and out on:

```
surf(peaks);
```

Note the range checking in the callback statements. This keeps the values for the camera view angle in the range, greater than zero and less than 180.

See Also

`axis`, `camproj`, `campos`, `camup`, `camtarget`

The axes properties `CameraPosition`, `CameraTarget`, `CameraUpVector`, `CameraViewAngle`, `Projection`

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

Purpose

Zoom in and out on a scene

Syntax

```
camzoom(zoom_factor)
camzoom(axes_handle,...)
```

Description

camzoom(zoom_factor) zooms in or out on the scene depending on the value specified by zoom_factor. If zoom_factor is greater than 1, the scene appears larger; if zoom_factor is greater than zero and less than 1, the scene appears smaller.

camzoom(axes_handle,...) operates on the axes identified by the first argument, axes_handle. When you do not specify an axes handle, camzoom operates on the current axes.

Remarks

camzoom sets the axes CameraViewAngle property, which in turn causes the CameraViewAngleMode property to be set to manual. Note that setting the CameraViewAngle property disables the MATLAB stretch-to-fill feature (stretching of the axes to fit the window). This may result in a change to the aspect ratio of your graph. See the axes function for more information on this behavior.

See Also

axes, camdolly, camorbit, campan, camroll, camva

"Controlling the Camera Viewpoint" for related functions

Defining Scenes with Camera Graphics for more information

capture

Purpose

`capture` is obsolete in Release 11 (5.3). `getframe` provides the same functionality and supports TrueColor displays by returning TrueColor images.

Syntax

```
capture
capture(h)
[X,cmap] = capture(h)
```

Description

`capture` creates a bitmap copy of the contents of the current figure, including any uicontrol graphics objects. It creates a new figure and displays the bitmap copy as an image graphics object in the new figure.

`capture(h)` creates a new figure that contains a copy of the figure identified by `h`.

`[X,cmap] = capture(h)` returns an image matrix `X` and a colormap. You display this information using the statements

```
colormap(cmap)
image(X)
```

Remarks

The resolution of a bitmap copy is less than that obtained with the `print` command.

See Also

`image`, `print`

“Figure Windows” for related functions

Purpose Transform Cartesian coordinates to polar or cylindrical

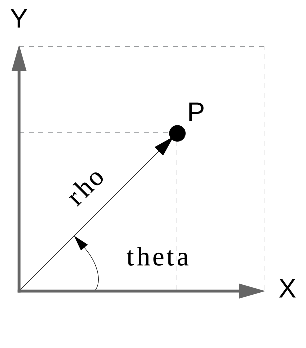
Syntax

```
[THETA,RHO,Z] = cart2pol(X,Y,Z)
[THETA,RHO] = cart2pol(X,Y)
```

Description `[THETA,RHO,Z] = cart2pol(X,Y,Z)` transforms three-dimensional Cartesian coordinates stored in corresponding elements of arrays `X`, `Y`, and `Z`, into cylindrical coordinates. `THETA` is a counterclockwise angular displacement in radians from the positive *x*-axis, `RHO` is the distance from the origin to a point in the *x*-*y* plane, and `Z` is the height above the *x*-*y* plane. Arrays `X`, `Y`, and `Z` must be the same size (or any can be scalar).

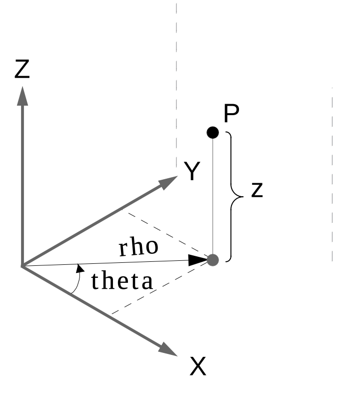
`[THETA,RHO] = cart2pol(X,Y)` transforms two-dimensional Cartesian coordinates stored in corresponding elements of arrays `X` and `Y` into polar coordinates.

Algorithm The mapping from two-dimensional Cartesian coordinates to polar coordinates, and from three-dimensional Cartesian coordinates to cylindrical coordinates is



Two-Dimensional Mapping

```
theta = atan2(y,x)
rho = sqrt(x.^2 + y.^2)
```



Three-Dimensional Mapping

```
theta = atan2(y,x)
rho = sqrt(x.^2 + y.^2)
z = z
```

See Also `cart2sph`, `pol2cart`, `sph2cart`

cart2sph

Purpose Transform Cartesian coordinates to spherical

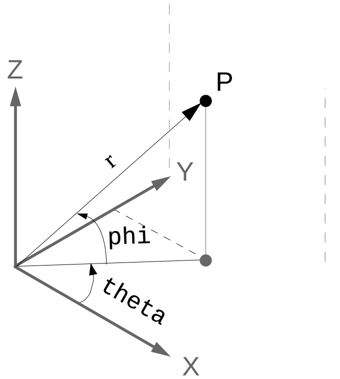
Syntax

```
[THETA,PHI,R] = cart2sph(X,Y,Z)
```

Description `[THETA,PHI,R] = cart2sph(X,Y,Z)` transforms Cartesian coordinates stored in corresponding elements of arrays `X`, `Y`, and `Z` into spherical coordinates. Azimuth `THETA` and elevation `PHI` are angular displacements in radians measured from the positive *x*-axis, and the *x*-*y* plane, respectively; and `R` is the distance from the origin to a point.

Arrays `X`, `Y`, and `Z` must be the same size.

Algorithm The mapping from three-dimensional Cartesian coordinates to spherical coordinates is




```
theta = atan2(y,x)
  phi = atan2(z, sqrt(x.^2 + y.^2))
    r = sqrt(x.^2+y.^2+z.^2)
```

See Also `cart2pol`, `pol2cart`, `sph2cart`

Purpose Case switch

Description `case` is part of the `switch` statement syntax, which allows for conditional execution.

A particular case consists of the `case` statement itself, followed by a case expression, and one or more statements.

A case is executed only if its associated case expression (`case_expr`) is the first to match the switch expression (`switch_expr`).

Examples The general form of the `switch` statement is:

```
switch switch_expr
    case case_expr
      statement,...,statement
    case {case_expr1,case_expr2,case_expr3,...}
      statement,...,statement
...
    otherwise
      statement,...,statement
 end
```

See Also `switch`

cat

Purpose

Concatenate arrays

Syntax

```
C = cat(dim,A,B)
C = cat(dim,A1,A2,A3,A4...)
```

Description

`C = cat(dim,A,B)` concatenates the arrays `A` and `B` along `dim`.

`C = cat(dim,A1,A2,A3,A4,...)` concatenates all the input arrays (`A1`, `A2`, `A3`, `A4`, and so on) along `dim`.

`cat(2,A,B)` is the same as `[A,B]` and `cat(1,A,B)` is the same as `[A;B]`.

Remarks

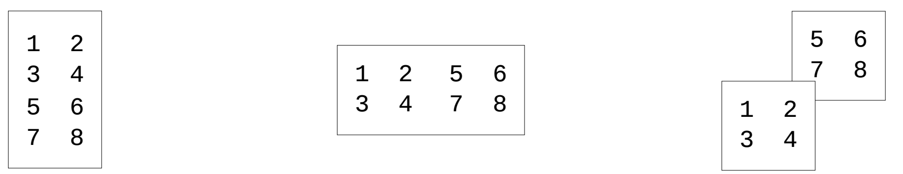
When used with comma separated list syntax, `cat(dim,C{:})` or `cat(dim,C.field)` is a convenient way to concatenate a cell or structure array containing numeric matrices into a single matrix.

Examples

Given,

```
A =                    B =
     1     2                     5     6
     3     4                     7     8
```

concatenating along different dimensions produces:



C = cat(1,A,B) **C = cat(2,A,B)** **C = cat(3,A,B)**

The commands

```
A = magic(3); B = pascal(3);
C = cat(4,A,B);
```

produce a 3-by-3-by-1-by-2 array.

See Also

`num2cell`

The special character `[]`

Purpose

Begin `catch` block

Description

The general form of a `try` statement is:

```
try,
   statement,
   ...,
   statement,
catch,
   statement,
   ...,
   statement,
end
```

Normally, only the statements between the `try` and `catch` are executed. However, if an error occurs while executing any of the statements, the error is captured into `lasterr`, and the statements between the `catch` and `end` are executed. If an error occurs within the `catch` statements, execution stops unless caught by another `try...catch` block. The error string produced by a failed `try` block can be obtained with `lasterr`.

See Also

`end`, `eval`, `evalin`, `try`

Purpose Color axis scaling

Syntax

```
caxis([cmin cmax])
caxis auto
caxis manual
caxis(caxis)
v = caxis
caxis(axes_handle,...)
```

Description

caxis controls the mapping of data values to the colormap. It affects any surfaces, patches, and images with indexed CData and CDataMapping set to scaled. It does not affect surfaces, patches, or images with true color CData or with CDataMapping set to direct.

caxis([cmin cmax]) sets the color limits to specified minimum and maximum values. Data values less than cmin or greater than cmax map to cmin and cmax, respectively. Values between cmin and cmax linearly map to the current colormap.

caxis auto lets MATLAB compute the color limits automatically using the minimum and maximum data values. This is the default behavior. Color values set to Inf map to the maximum color, and values set to –Inf map to the minimum color. Faces or edges with color values set to NaN are not drawn.

caxis manual and caxis(caxis) freeze the color axis scaling at the current limits. This enables subsequent plots to use the same limits when hold is on.

v = caxis returns a two-element row vector containing the [cmin cmax] currently in use.

caxis(axes_handle,...) uses the axes specified by axes_handle instead of the current axes.

Remarks

caxis changes the CLim and CLimMode properties of axes graphics objects.

How Color Axis Scaling Works

Surface, patch, and image graphics objects having indexed CData and CDataMapping set to scaled, map CData values to colors in the figure colormap each time they render. CData values equal to or less than cmin map to the first color value in the colormap, and `CData` values equal to or greater than `cmax` map to the last color value in the colormap. MATLAB performs the following linear transformation on the intermediate values (referred to as `C` below) to map them to an entry in the colormap (whose length is `m`, and whose row index is referred to as `index` below).

```
index = fix((C-cmin)/(cmax-cmin)*m)+1
```

Examples

Create `(X,Y,Z)` data for a sphere and view the data as a surface.

```
[X,Y,Z] = sphere;
C = Z;
surf(X,Y,Z,C)
```

Values of `C` have the range [–1 1]. Values of `C` near –1 are assigned the lowest values in the colormap; values of `C` near 1 are assigned the highest values in the colormap.

To map the top half of the surface to the highest value in the color table, use

```
caxis([-1 0])
```

To use only the bottom half of the color table, enter

```
caxis([-1 3])
```

which maps the lowest `CData` values to the bottom of the colormap, and the highest values to the middle of the colormap (by specifying a `cmax` whose value is equal to `cmin` plus twice the range of the `CData`).

The command

```
caxis auto
```

resets axis scaling back to auto-ranging and you see all the colors in the surface. In this case, entering

```
caxis
```

returns

```
[-1 1]
```

Adjusting the color axis can be useful when using images with scaled color data. For example, load the image data and colormap for Cape Cod, Massachusetts.

```
load cape
```

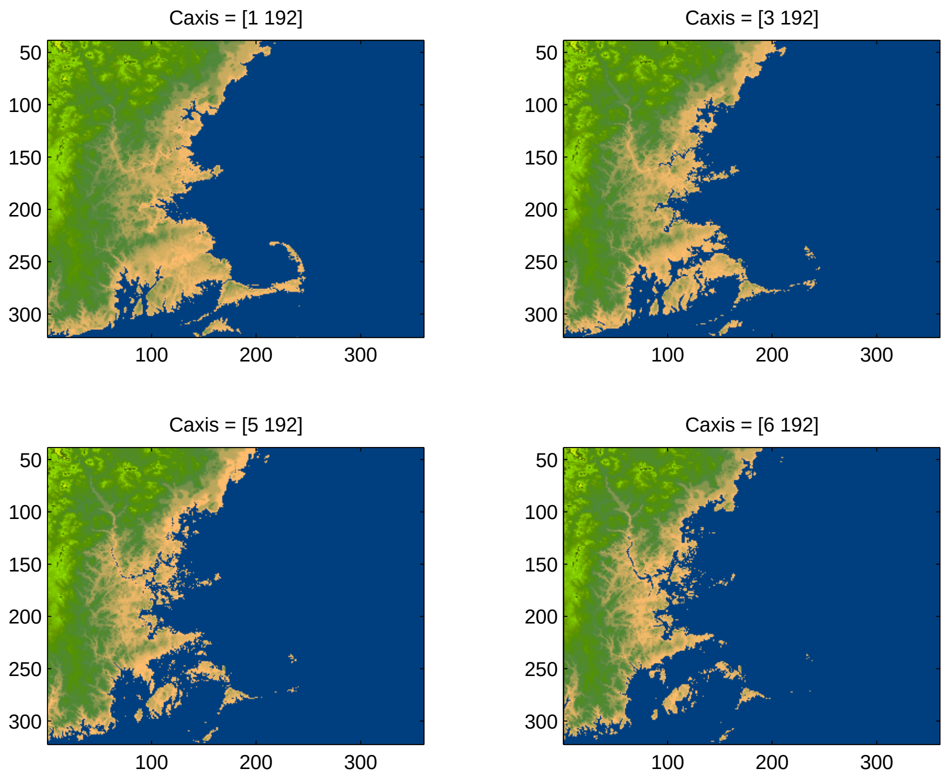
This command loads the images data `X` and the image's colormap `map` into the workspace. Now display the image with `CDataMapping` set to `scaled` and install the image's colormap.

```
image(X,'CDataMapping','scaled')
colormap(map)
```

MATLAB sets the color limits to span the range of the image data, which is 1 to 192:

```
caxis
ans =
     1   192
```

The blue color of the ocean is the first color in the colormap and is mapped to the lowest data value (1). You can effectively move sealevel by changing the lower color limit value. For example,



See Also

`axes`, `axis`, `colormap`, `get`, `mesh`, `pcolor`, `set`, `surf`

The `CLim` and `CLimMode` properties of axes graphics objects.

The `Colormap` property of figure graphics objects.

"Color Operations" for related functions

Axes Color Limits for more examples

Purpose Change working directory

Graphical Interface As an alternative to the `cd` function, use the **Current Directory** field in the MATLAB desktop toolbar.

Syntax

```
cd
w = cd
cd('directory')
cd('..')
cd directory or cd ..
```

Description `cd` displays the current working directory.

`w = cd` assigns the current working directory to `w`.

`cd('directory')` sets the current working directory to `directory`. Use the full pathname for `directory`. On UNIX platforms, the character ~ is interpreted as the user's root directory.

`cd('..')` changes the current working directory to the directory above it.

`cd directory` or `cd ..` is the unquoted form of the syntax.

Examples On UNIX

```
cd('/usr/local/matlab/toolbox/demos')
```

changes the current working directory to `demos`.

On Windows

```
cd('c:/toolbox/matlab/demos')
```

changes the current working directory to `demos`. Then typing

```
cd ..
```

changes the current working directory to `matlab`.

See Also `dir`, `path`, `pwd`, `what`

Purpose Convert complex diagonal form to real block diagonal form

Syntax

```
[V,D] = cdf2rdf(V,D)
```

Description If the eigensystem `[V,D] = eig(X)` has complex eigenvalues appearing in complex-conjugate pairs, `cdf2rdf` transforms the system so `D` is in real diagonal form, with 2-by-2 real blocks along the diagonal replacing the complex pairs originally there. The eigenvectors are transformed so that

```
X = V*D/V
```

continues to hold. The individual columns of `V` are no longer eigenvectors, but each pair of vectors associated with a 2-by-2 block in `D` spans the corresponding invariant vectors.

Examples The matrix

```
X =
    1     2     3
    0     4     5
    0    -5     4
```

has a pair of complex eigenvalues.

```
[V,D] = eig(X)

V =

    1.0000      -0.0191 - 0.4002i     -0.0191 + 0.4002i
         0            0 - 0.6479i           0 + 0.6479i
         0       0.6479                0.6479

D =

    1.0000            0                     0
         0       4.0000 + 5.0000i           0
         0            0                4.0000 - 5.0000i
```

Converting this to real block diagonal form produces

```
[V,D] = cdf2rdf(V,D)
```

```
V =

    1.0000   -0.0191   -0.4002
         0         0   -0.6479
         0    0.6479         0

D =

    1.0000         0         0
         0    4.0000    5.0000
         0   -5.0000    4.0000
```

Algorithm

The real diagonal form for the eigenvalues is obtained from the complex form using a specially constructed similarity transformation.

See Also

`eig`, `rsf2csf`

Purpose Construct a cdfepoch object for Common Data Format (CDF) export

Syntax

```
E = cdfepoch(date)
```

Description `E = cdfepoch(date)` constructs a `cdfepoch` object, where `date` is a valid string (`datestr`), a number (`datenum`) representing a date, or a `cdfepoch` object.

When writing data to a CDF using `cdfwrite`, use `cdfepoch` to convert MATLAB formatted dates to CDF formatted dates. The MATLAB `cdfepoch` object simulates the `CDFEPOCH` datatype in CDF files

---

Note A CDF epoch is the number of milliseconds since 1-Jan-0000. MATLAB `datenums` are the number of days since 0-Jan-0000.

See also `cdfinfo`, `cdfread`, `cdfwrite`, `datenum`

cdfinfo

Purpose Return information about a CDF file

Syntax

```
info = cdfinfo(file)
```

Description

`info = cdfinfo(file)` returns information about the Common Data Format (CDF) file specified in the string, `file`. The function returns a structure, `info`, that contains the fields shown in the following table.

Field	Description	Return Type
`FileModDate`	Date the file was last modified	String
`Filename`	Name of the file	String
`FileSettings`	Library settings used to create the file	Structure array
`FileSize`	Size of the file, in bytes	Double
`Format`	File format (CDF)	String
`FormatVersion`	Version of the CDF library used to create the file	String
`GlobalAttributes`	Global metadata	Structure array
`Subfiles`	Filenames containing the CDF file's data, if it is a multifile CDF	Cell array
`VariableAttributes`	Metadata for the variables	Structure array
`Variables`	Details about the variables in the file	Cell array

The GlobalAttributes and VariableAttributes Fields

`GlobalAttributes` and `VariableAttributes` are structure arrays that each contain one field for each global or variable attribute respectively. The name of the field corresponds to the name of an attribute. The data in that field, contained in a cell array, represents the entry values for that attribute.

For `VariableAttributes`, the attribute data resides in an N-by-2 cell array, where N is the number of variables. The first column of this cell array contains the variable names associated with the entries. The second column contains the entry values.

Note Attribute names may not match the names of the attributes in the CDF file exactly. Because attribute names can contain characters that are illegal in MATLAB field names, they may be translated into legal field names. Illegal characters that appear at the beginning of attributes are removed; other illegal characters are replaced with underscores ('_'). If an attribute's name is modified, the attribute's internal number is appended to the end of the field name. For example, `Variable%Attribute` might become `Variable_Attribute_013`.

The Variables Field

The `Variables` field of the returned `info` structure is an N-by-6 cell array, where N is the number of variables. The six columns of the cell array contain the following information.

Column No.	Description	Return Type
1	Name of the variable	String
2	Dimensions of the variable, as returned by the `size` function	Double array
3	Number of records assigned for the variable	Double
4	Data type of the variable, as stored in the CDF file	String

Column No.	Description	Return Type

5	Record and dimension variance settings for the variable. The single `T` or `F` to the left of the slash designates whether values vary by record. The zero or more `T` or `F` letters to the right of the slash designate whether values vary at each dimension. Here are some examples.
	`T/     (scalar variable)`
	`F/T    (one-dimensional variable)`
	`T/TFF  (three-dimensional variable)`
		String

6	Sparsity of the variable's records. This is a string holding one of three possible values: • `'Full'` • `'Sparse (padded)'` • `'Sparse (nearest)'`	String

Examples

```
info = cdfinfo('example.cdf')
info =
              Filename: 'example.cdf'
           FileModDate: '29-Jun-1995 05:51:58'
              FileSize: 230513
                Format: 'CDF'
         FormatVersion: '2.4.8'
          FileSettings: [1x1 struct]
              Subfiles: {}
             Variables: {7x6 cell}
      GlobalAttributes: [1x1 struct]
    VariableAttributes: [1x1 struct]

info.Variables
ans =
    'L_gse'         [1x2 double]   [   1]   'char'     'F/T'  'Full'
    'Status%C1'     [1x2 double]   [7493]   'uint8'    'T/T'  'Full'
    'B_gse%C1'      [1x2 double]   [7493]   'single'   'T/T'  'Full'
    'B_nsigma%C1'   [1x2 double]   [7493]   'single'   'T/'   'Full'
```

See Also `cdfread`

cdfread

Purpose Read data from a CDF file

Syntax

```
data = cdfread(file)
data = cdfread(file, 'records', recnums, ...)
data = cdfread(file, 'variables', varnames, ...)
data = cdfread(file, 'slices', dimensionvalues, ...)
[data, info] = cdfread(file, ...)
```

Description

`data = cdfread(file)` reads all of the variables from each record of the Common Data Format (CDF) file specified in the string, `file`. The return value, `data`, is a cell array in which each row contains a record and each column represents a variable.

`data = cdfread(file, 'records', recnums, ...)` reads only those records specified in the vector, `recnums`. The record numbers are zero-based. The return value, `data`, is a cell array having `length(recnums)` number of rows and as many columns as there are variables.

`data = cdfread(file, 'variables', varnames, ...)` reads only those variables specified in the 1-by-N or N-by-1 cell array of strings, `varnames`. The return alue, `data`, is returned in a cell array having `length(varnames)` number of columns and a row for each record requested.

`data = cdfread(file, 'slices', dimensionvalues, ...)` reads specific values from the records of one variable in the CDF file. The N-by-3 matrix, `dimensionvalues`, indicates which records are to be read by specifying `start`, `interval`, and `count` parameters for each of the N dimensions of the variable. The `start` parameter is zero-based.

The number of rows in `dimensionvalues` must be less than or equal to the number of dimensions of the variable. Unspecified rows default to `[0 1 N]`, where `N` is the total number of values in a record. This causes `cdfread` to read every value from those dimensions.

Because you can read just one variable at a time, you must also include a `'variables'` parameter with this syntax.

`[data, info] = cdfread(file, ...)` also returns details about the CDF file in the `info` structure.

Examples

Read all of the data from the file.

```
data = cdfread('example.cdf');
```

Read just the data from variable 'Time'.

```
data = cdfread('example.cdf', 'Variable', {'Time'});
```

Read the first value in the first dimension, the second value in the second dimension, the first and third values in the third dimension, and all values in the remaining dimension of the variable 'multidimensional'.

```
data = cdfread('example.cdf', 'Variable', ...
{'multidimensional'}, 'Slices', [0 1 1; 1 1 1; 0 2 2]);
```

This is similar to reading the whole variable into 'data', and then using the MATLAB command

```
data{1}(1, 2, [1 3], :)
```

See Also

cdfinfo, cdfwrite, cdfepoch

cdfwrite

Purpose Write data to a CDF file

Syntax

```
cdfwrite(file, variablelist)
cdfwrite(..., 'PadValues', padvals)
cdfwrite(..., 'GlobalAttributes', gattrib)
cdfwrite(..., 'VariableAttributes', vattrib)
cdfwrite(..., 'WriteMode', mode)
cdfwrite(..., 'Format', format)
```

Description

`cdfwrite(file,variablelist)` writes out a Common Data Format (CDF) file, specified in the string, `file`. The `variablelist` argument is a cell array of ordered pairs, which are comprised of a CDF variable name (a string) and the corresponding CDF variable value. To write out multiple records for a variable, put the values in a cell array, where each element in the cell array represents a record.

`cdfwrite(...,'PadValues',padvals)` writes out pad values for given variable names. `padvals` is a cell array of ordered pairs, which are comprised of a variable name (a string) and a corresponding pad value. Pad values are the default value associated with the variable when an out-of-bounds record is accessed. Variable names that appear in `padvals` must appear in `variablelist`.

`cdfwrite(...,'GlobalAttributes',gattrib)` writes the structure `gattrib` as global metadata for the CDF file. Each field of the structure is the name of a global attribute. The value of each field contains the value of the attribute. To write out multiple values for an attribute, put the values in a cell array where each element in the cell array represents a record.

Note To specify a global attribute name that is illegal in MATLAB, create a field called `'CDFAttributeRename'` in the attribute structure. The value of this field must have a value that is a cell array of ordered pairs. The ordered pair consists of the name of the original attribute, as listed in the GlobalAttributes structure and the corresponding name of the attribute to be written to the CDF file.

`cdfwrite(..., 'VariableAttributes', vattrib)` writes the structure `vattrib` as variable metadata for the CDF. Each field of the struct is the name of a variable attribute. The value of each field should be an M-by-2 cell array where M is the number of variables with attributes. The first element in the cell array should be the name of the variable and the second element should be the value of the attribute for that variable.

Note To specify a variable attribute name that is illegal in MATLAB, create a field called `'CDFAttributeRename'` in the attribute structure. The value of this field must have a value that is a cell array of ordered pairs. The ordered pair consists of the name of the original attribute, as listed in the `VariableAttributes` struct, and the corresponding name of the attribute to be written to the CDF file. If you are specifying a variable attribute of a CDF variable that you are renaming, the name of the variable in the `VariableAttributes` structure must be the same as the renamed variable.

`cdfwrite(...,'WriteMode',`*`mode`*`)` where *`mode`* is either `'overwrite'` or `'append'`, indicates whether or not the specified variables should be appended to the CDF file if the file already exists. By default, `cdfwrite` overwrites existing variables and attributes.,

`cdfwrite(...,'Format',`*`format`*`)` where *`format`* is either `'multifile'` or `'singlefile'`, indicates whether or not the data is written out as a multifile CDF. In a multifile CDF, each variable is stored in a separate file with the name `*.vN`, where `N` is the number of the variable that is written out to the CDF. By default, `cdfwrite` writes out a single file CDF. When `'WriteMode'` is set to `'Append'`, the `'Format'` option is ignored, and the format of the pre-existing CDF is used.

Examples

Write out a file `'example.cdf'` containing a variable `'Longitude'` with the value `[0:360]`.

```
cdfwrite('example', {'Longitude', 0:360});
```

Write out a file `'example.cdf'` containing variables `'Longitude'` and `'Latitude'` with the variable `'Latitude'` having a pad value of 10 for all out-of-bounds records that are accessed.

```
cdfwrite('example', {'Longitude', 0:360, 'Latitude', 10:20},...
                    'PadValues', {'Latitude', 10});
```

Write out a file 'example.cdf', containing a variable 'Longitude' with the value [0:360], and with a variable attribute of 'validmin' with the value 10.

```
varAttribStruct.validmin = {'longitude' [10]};
cdfwrite('example', {'Longitude' 0:360}, 'VarAttribStruct',...
                    varAttribStruct);
```

See Also cdfread, cdfinfo, cdfepoch

Purpose

Round toward infinity

Syntax

```
B = ceil(A)
```

Description

`B = ceil(A)` rounds the elements of `A` to the nearest integers greater than or equal to `A`. For complex `A`, the imaginary and real parts are rounded independently.

Examples

```
a = [-1.9, -0.2, 3.4, 5.6, 7, 2.4+3.6i]

a =
  Columns 1 through 4
 -1.9000         -0.2000           3.4000           5.6000

  Columns 5 through 6
   7.0000             2.4000 + 3.6000i

ceil(a)

ans =
  Columns 1 through 4
  -1.0000          0             4.0000             6.0000

  Columns 5 through 6
   7.0000             3.0000 + 4.0000i
```

See Also

`fix`, `floor`, `round`

Purpose Create cell array

Syntax

```
c = cell(n)
c = cell(m,n) or c = cell([m n])
c = cell(m,n,p,...) or c = cell([m n p ...])
c = cell(size(A))
c = cell(javaobj)
```

Description

`c = cell(n)` creates an n-by-n cell array of empty matrices. An error message appears if `n` is not a scalar.

`c = cell(m,n)` or `c = cell([m,n])` creates an m-by-n cell array of empty matrices. Arguments `m` and `n` must be scalars.

`c = cell(m,n,p,...)` or `c = cell([m n p ...])` creates an m-by-n-by-p-... cell array of empty matrices. Arguments `m`, `n`, `p`,... must be scalars.

`c = cell(size(A))` creates a cell array the same size as `A` containing all empty matrices.

`c = cell(javaobj)` converts a Java array or Java object, `javaobj`, into a MATLAB cell array. Elements of the resulting cell array will be of the MATLAB type (if any) closest to the Java array elements or Java object.

Examples

This example creates a cell array that is the same size as another array, `A`.

```
A = ones(2,2)

A =
     1     1
     1     1

c = cell(size(A))

c =
     []     []
     []     []
```

The next example converts an array of `java.lang.String` objects into a MATLAB cell array.

```
strArray = java_array('java.lang.String',3);
strArray(1) = java.lang.String('one');
strArray(2) = java.lang.String('two');
strArray(3) = java.lang.String('three');

cellArray = cell(strArray)
cellArray =
    'one'
    'two'
    'three'
```

See Also

`num2cell`, `ones`, `rand`, `randn`, `zeros`

Purpose

Convert cell array of matrices into single matrix

Syntax

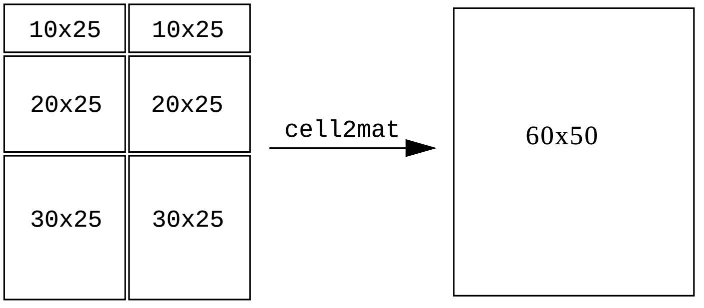
```
m = cell2mat(c)
```

Description

`m = cell2mat(c)` converts a multidimensional cell array, `c`, with contents of the same data type into a single matrix, `m`. The contents of `c` must be able to concatenate into a hyperrectangle. Moreover, for each pair of neighboring cells, the dimensions of the cell's contents must match, excluding the dimension in which the cells are neighbors.

The example shown below combines matrices in a 3-by-2 cell array into a single 60-by-50 matrix:

```
cell2mat(c)
```



Remarks

The dimensionality (or number of dimensions) of `m` will match the highest dimensionality contained in the cell array.

`cell2mat` is not supported for cell arrays containing cell arrays or objects.

Examples

Combine the matrices in four cells of cell array `C` into the single matrix, `M`:

```
C = {[1] [2 3 4]; [5; 9] [6 7 8; 10 11 12]}
C =
    [         1]    [1x3 double]
    [2x1 double]    [2x3 double]
```

```
C{1,1}                       C{1,2}
ans =                        ans =
     1                            2     3     4

C{2,1}                       C{2,2}
ans =                        ans =
     5                            6     7     8
     9                           10    11    12

M = cell2mat(C)
M =
     1     2     3     4
     5     6     7     8
     9    10    11    12
```

See Also `mat2cell`, `num2cell`

cell2struct

Purpose

Convert cell array to structure array

Syntax

```
s = cell2struct(c,fields,dim)
```

Description

`s = cell2struct(c,fields,dim)` creates a structure array, `s`, from the information contained within cell array, `c`.

The `fields` argument specifies field names for the structure array. `fields` can be a character array or a cell array of strings.

The `dim` argument controls which axis of the cell array is to be used in creating the structure array. The length of `c` along the specified dimension must match the number of fields named in `fields`. In other words, the following must be true.

```
size(c,dim) == length(fields)       % if fields is a cell array
size(c,dim) == size(fields,1)       % if fields is a char array
```

Examples

The cell array, `c`, in this example contains information on trees. The three columns of the array indicate the common name, genus, and average height of a tree.

```
c = {'birch','betula',65;  'maple','acer',50}
c =
    'birch'    'betula'    [65]
    'maple'    'acer'      [50]
```

To put this information into a structure with the fields `name`, `genus`, and `height`, use `cell2struct` along the second dimension of the 2-by-3 cell array.

```
fields = {'name', 'genus', 'height'};
s = cell2struct(c, fields, 2);
```

This yields the following 2-by-1 structure array.

```
s(1)                           s(2)
ans =                          ans =
      name: 'birch'                  name: 'maple'
     genus: 'betula'                genus: 'acer'
    height: 65                     height: 50
```

See Also

`fieldnames`, `struct2cell`

Purpose

Display cell array contents.

Syntax

```
celldisp(C)
celldisp(C,name)
```

Description

`celldisp(C)` recursively displays the contents of a cell array.

`celldisp(C,`*`name`*`)` uses the string *`name`* for the display instead of the name of the first input (or `ans`).

Example

Use `celldisp` to display the contents of a 2-by-3 cell array:

```
C = {[1 2] 'Tony' 3+4i; [1 2;3 4] -5 'abc'};
celldisp(C)

C{1,1} =
     1     2

C{2,1} =
     1     2
     3     4

C{1,2} =
Tony

C{2,2} =
    -5

C{1,3} =
   3.0000+ 4.0000i

C{2,3} =
abc
```

See Also

`cellplot`

Purpose

Apply a function to each element in a cell array

Syntax

```
D = cellfun('fname',C)
D = cellfun('size',C,k)
D = cellfun('isclass',C,classname)
```

Description

`D = cellfun('fname',C)` applies the function `fname` to the elements of the cell array `C` and returns the results in the double array `D`. Each element of `D` contains the value returned by `fname` for the corresponding element in `C`. The output array `D` is the same size as the cell array `C`.

These functions are supported:

Function	Return Value
`isempty`	`true` for an empty cell element
`islogical`	`true` for a logical cell element
`isreal`	`true` for a real cell element
`length`	Length of the cell element
`ndims`	Number of dimensions of the cell element
`prodofsize`	Number of elements in the cell element

`D = cellfun('size',C,k)` returns the size along the `k`-th dimension of each element of `C`.

`D = cellfun('isclass',C,'classname')` returns `true` for each element of `C` that matches `classname`. This function syntax returns `false` for objects that are a subclass of `classname`.

Limitations

If the cell array contains objects, `cellfun` does not call overloaded versions of the function `fname`.

Example

Consider this 2-by-3 cell array:

```
C{1,1} = [1 2; 4 5];
C{1,2} = 'Name';
```

```
C{1,3} = pi;
C{2,1} = 2 + 4i;
C{2,2} = 7;
C{2,3} = magic(3);
```

`cellfun` returns a 2-by-3 double array:

```
D = cellfun('isreal',C)

D =
     1     1     1
     0     1     1

len = cellfun('length',C)

len =
     2     4     1
     1     1     3

isdbl = cellfun('isclass',C,'double')

isdbl =
     1     0     1
     1     1     1
```

See Also `isempty`, `islogical`, `isreal`, `length`, `ndims`, `size`

Purpose Graphically display the structure of cell arrays

Syntax

```
cellplot(c)
cellplot(c,'legend')
handles = cellplot(...)
```

Description `cellplot(c)` displays a figure window that graphically represents the contents of `c`. Filled rectangles represent elements of vectors and arrays, while scalars and short text strings are displayed as text.

`cellplot(c,'legend')` also puts a legend next to the plot.

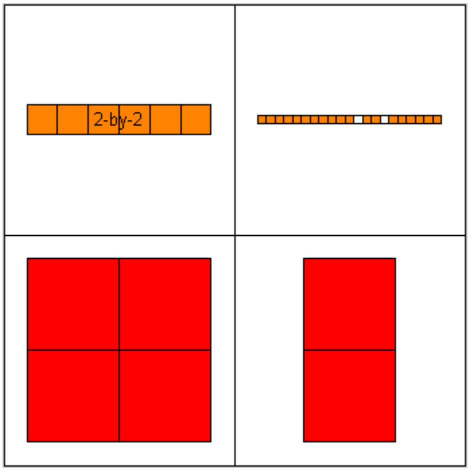
`handles = cellplot(c)` displays a figure window and returns a vector of surface handles.

Limitations The `cellplot` function can display only two-dimensional cell arrays.

Examples Consider a 2-by-2 cell array containing a matrix, a vector, and two text strings:

```
c{1,1} = '2-by-2';
c{1,2} = 'eigenvalues of eye(2)';
c{2,1} = eye(2);
c{2,2} = eig(eye(2));
```

The command `cellplot(c)` produces:



Purpose Create cell array of strings from character array

Syntax

```
c = cellstr(S)
```

Description

`c = cellstr(S)` places each row of the character array `S` into separate cells of `c`. Use the `char` function to convert back to a string matrix.

Examples

Given the string matrix

```
S=['abc ';'defg';'hi  ']

S =
    abc
    defg
    hi

whos S
  Name      Size         Bytes  Class
  S         3x4             24  char array
```

The following command returns a 3-by-1 cell array.

```
c = cellstr(S)

c =
    'abc'
    'defg'
    'hi'

whos c
  Name      Size         Bytes  Class
  c         3x1            294  cell array
```

See Also

`iscellstr`, `strings`

Purpose

Conjugate Gradients Squared method

Syntax

```
x = cgs(A,b)
cgs(A,b,tol)
cgs(A,b,tol,maxit)
cgs(A,b,tol,maxit,M)
cgs(A,b,tol,maxit,M1,M2)
cgs(A,b,tol,maxit,M1,M2,x0)
cgs(afun,b,tol,maxit,m1fun,m2fun,x0,p1,p2,...)
[x,flag] = cgs(A,b,...)
[x,flag,relres] = cgs(A,b,...)
[x,flag,relres,iter] = cgs(A,b,...)
[x,flag,relres,iter,resvec] = cgs(A,b,...)
```

Description

`x = cgs(A,b)` attempts to solve the system of linear equations `A*x = b` for `x`. The `n`-by-`n` coefficient matrix `A` must be square and should be large and sparse. The column vector `b` must have length `n`. `A` can be a function `afun` such that `afun(x)` returns `A*x`.

If `cgs` converges, a message to that effect is displayed. If `cgs` fails to converge after the maximum number of iterations or halts for any reason, a warning message is printed displaying the relative residual `norm(b-A*x)/norm(b)` and the iteration number at which the method stopped or failed.

`cgs(A,b,tol)` specifies the tolerance of the method, `tol`. If `tol` is `[]`, then `cgs` uses the default, `1e-6`.

`cgs(A,b,tol,maxit)` specifies the maximum number of iterations, `maxit`. If `maxit` is `[]` then `cgs` uses the default, `min(n,20)`.

`cgs(A,b,tol,maxit,M)` and `cgs(A,b,tol,maxit,M1,M2)` use the preconditioner `M` or `M = M1*M2` and effectively solve the system `inv(M)*A*x = inv(M)*b` for `x`. If `M` is `[]` then `cgs` applies no preconditioner. `M` can be a function `that` returns `M\x`.

`cgs(A,b,tol,maxit,M1,M2,x0)` specifies the initial guess `x0`. If `x0` is `[]`, then `cgs` uses the default, an all-zero vector.

cgs(afun,b,tol,maxit,m1fun,m2fun,x0,p1,p2,...) passes parameters p1,p2,... to functions afun(x,p1,p2,...), m1fun(x,p1,p2,...), and m2fun(x,p1,p2,...)

[x,flag] = cgs(A,b,...) returns a solution x and a flag that describes the convergence of cgs.

Flag	Convergence
0	cgs converged to the desired tolerance tol within maxit iterations.
1	cgs iterated maxit times but did not converge.
2	Preconditioner M was ill-conditioned.
3	cgs stagnated. (Two consecutive iterates were the same.)
4	One of the scalar quantities calculated during cgs became too small or too large to continue computing.

Whenever flag is not 0, the solution x returned is that with minimal norm residual computed over all the iterations. No messages are displayed if the flag output is specified.

[x,flag,relres] = cgs(A,b,...) also returns the relative residual norm(b-A*x)/norm(b). If flag is 0, then relres <= tol.

[x,flag,relres,iter] = cgs(A,b,...) also returns the iteration number at which x was computed, where 0 <= iter <= maxit.

[x,flag,relres,iter,resvec] = cgs(A,b,...) also returns a vector of the residual norms at each iteration, including norm(b-A*x0).

Examples

Example 1.

```
A = gallery('wilk',21);
b = sum(A,2);
tol = 1e-12;  maxit = 15;
M1 = diag([10:-1:1 1 1:10]);
x = cgs(A,b,tol,maxit,M1,[],[]);
```

Alternatively, use this matrix-vector product function

```
function y = afun(x,n)
y = [ 0;
      x(1:n-1)] + [((n-1)/2:-1:0)';
      (1:(n-1)/2)'] .*x + [x(2:n);
      0 ];
```

and this preconditioner backsolve function

```
function y = mfun(r,n)
y = r ./ [((n-1)/2:-1:1)'; 1; (1:(n-1)/2)'];
```

as inputs to `cgs`.

```
x1 = cgs(@afun,b,tol,maxit,@mfun,[],[],21);
```

Note that both `afun` and `mfun` must accept `cgs`'s extra input `n=21`.

Example 2.

```
load west0479
A = west0479
b = sum(A,2)
[x,flag] = cgs(A,b)
```

`flag` is `1` because `cgs` does not converge to the default tolerance `1e-6` within the default 20 iterations.

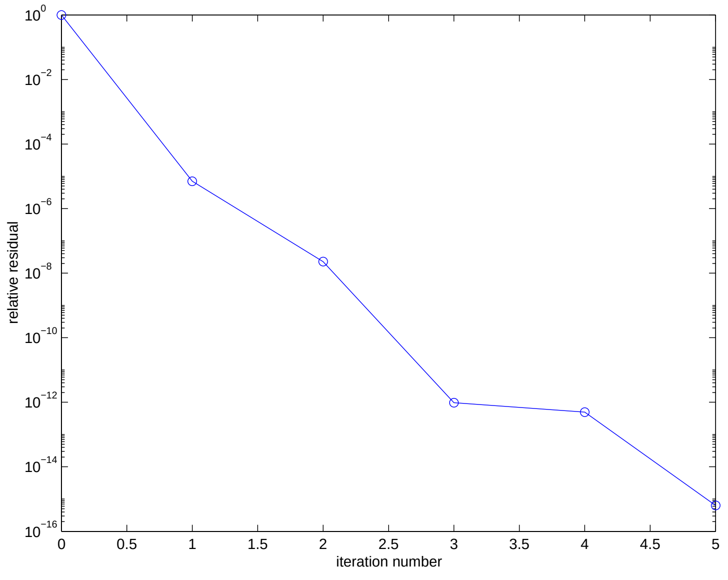
```
[L1,U1] = luinc(A,1e-5)
[x1,flag1] = cgs(A,b,1e-6,20,L1,U1)
```

`flag1` is `2` because the upper triangular `U1` has a zero on its diagonal, and `cgs` fails in the first iteration when it tries to solve a system such as `U1*y = r` for `y` with backslash.

```
[L2,U2] = luinc(A,1e-6)
[x2,flag2,relres2,iter2,resvec2] = cgs(A,b,1e-15,10,L2,U2)
```

`flag2` is `0` because `cgs` converges to the tolerance of `6.344e-16` (the value of `relres2`) at the fifth iteration (the value of `iter2`) when preconditioned by the incomplete LU factorization with a drop tolerance of `1e-6`. `resvec2(1) = norm(b)` and `resvec2(6) = norm(b-A*x2)`. You can follow the progress of cgs by plotting the relative residuals at each iteration starting from the initial estimate (iterate number 0) with

```
semilogy(0:iter2,resvec2/norm(b),'-o')
xlabel('iteration number')
ylabel('relative residual')
```



See Also

bicg, bicgstab, gmres, lsqr, luinc, minres, pcg, qmr, symmlq

@ (function handle), \ (backslash)

References

[1] Barrett, R., M. Berry, T. F. Chan, et al., *Templates for the Solution of Linear Systems: Building Blocks for Iterative Methods*, SIAM, Philadelphia, 1994.

[2] Sonneveld, Peter, “CGS: A fast Lanczos-type solver for nonsymmetric linear systems”, *SIAM J. Sci. Stat. Comput.*, January 1989, Vol. 10, No. 1, pp. 36-52.

Purpose

Create character array (string)

Syntax

```
S = char(X)
S = char(C)
S = char(t1,t2,t3...)
```

Description

`S = char(X)` converts the array `X` that contains positive integers representing character codes into a MATLAB character array (the first 127 codes are ASCII). The actual characters displayed depend on the character set encoding for a given font. The result for any elements of `X` outside the range from 0 to 65535 is not defined (and may vary from platform to platform). Use `double` to convert a character array into its numeric codes.

`S = char(C)` when `C` is a cell array of strings, places each element of `C` into the rows of the character array `s`. Use `cellstr` to convert back.

`S = char(t1,t2,t3,..)` forms the character array `S` containing the text strings `T1`,`T2`,`T3`,... as rows, automatically padding each string with blanks to form a valid matrix. Each text parameter, `T`*`i`*, can itself be a character array. This allows the creation of arbitrarily large character arrays. Empty strings are significant.

Remarks

Ordinarily, the elements of `A` are integers in the range 32:127, which are the printable ASCII characters, or in the range 0:255, which are all 8-bit values. For noninteger values, or values outside the range 0:255, the characters printed are determined by `fix(rem(A,256))`.

Examples

To print a 3-by-32 display of the printable ASCII characters:

```
ascii = char(reshape(32:127,32,3)')
ascii =
! " # $ % & ' ( ) *+ , - . / 0 1 2 3 4 5 6 7 8 9 : ; < = > ?
@ A B C D E F G H I J K L M N O P Q R S T U V W X Y Z [ \ ] ^ _
' a b c d e f g h i j k l m n o p q r s t u v w x y z { | } ~
```

See Also `cellstr`, `double`, `get`, `set`, `strings`, `strvcat`, `text`

Purpose Check file into source control system

Graphical Interface As an alternative to the checkin function, use **Source Control Check In** in the Editor, Simulink, or Stateflow **File** menu.

Syntax

```
checkin('filename','comments','string')
checkin({'filename1','filename2','filename3', ...},'comments',
   'string')
checkin('filename','option','value', ...)
```

Description

`checkin('filename','comments','string')` checks in the file named `filename` to the source control system. Use the full pathname for the `filename`. You must save the file before checking it in. The file can be open or closed when you use `checkin`. The `string` argument is a MATLAB string containing check-in comments for the source control system. You must supply the **`comments`** argument and `'string'`.

`checkin({'filename1','filename2','filename3', ...},'comments', 'string')` checks in the files named `filename1` through `filenamen` to the source control system. Use the full pathnames for the files. Additional arguments apply to all files checked in.

`checkin('filename','option','value', ...)` provides additional `checkin` options. The *`option`* and *`value`* arguments are shown in the table below.

option Argument	Purpose	value Argument
`'force'`	When set to on, `filename` is checked in even if the file has not changed since it was checked out. The default value for `force` is `off`.	`'on'` `'off'` (default)
`'lock'`	When set to on, `filename` remains checked out. Comments are submitted. The default value for `lock` is `off`.	`'on'` `'off'` (default)

You can check in a file that you checked out in a previous MATLAB session or that you checked out directly from your source control system.

Examples

Check in a File with Comments

Typing

```
checkin('/matlab/mymfiles/clock.m','comments','Adjustment for
Y2K')
```

checks in the file `/matlab/mymfiles/clock.m` to the source control system with the comment `Adjustment for Y2K`.

Check in Multiple Files with Comments

Typing

```
checkin({'/matlab/mymfiles/clock.m', ...
'/matlab/mymfiles/calendar.m'},'comments','Adjustment for Y2K')
```

checks two files into the source control system using the same comment for each.

Check a File in and Keep It Checked out

Typing

```
checkin('/matlab/mymfiles/clock.m','comments','Adjustment for
Y2K','lock','on')
```

checks the file `/matlab/mymfiles/clock.m` into the source control system and keeps the file checked out.

See Also

`checkout`, `cmopts`, `undocheckout`

checkout

Purpose Check file out of source control system

Graphical Interface As an alternative to the `checkout` function, use **Source Control Check Out** in the Editor, Simulink, or Stateflow **File** menu.

Syntax

```
checkout('filename')
checkout({'filename1','filename2','filename3', ...})
checkout('filename','option','value', ...)
```

Description

`checkout('filename')` checks out the file named `filename` from the source control system. `filename` must be the full pathname for the file. The file can be open or closed when you use `checkout`.

`checkout({'filename1','filename2','filename3', ...})` checks out the files named `filename1` through `filenamen` from the source control system. Use the full pathnames for the files. Additional arguments apply to all files checked out.

`checkout('filename','`*`option`*`','value', ...)` provides additional `checkout` options. The *`option`* and *`value`* arguments are shown in the following table.

option Argument	Purpose	value Argument
'force'	When set to on, the checkout is forced, even if you already have the file checked out. This is effectively an `undocheckout` followed by a `checkout`. When `force` is set to `off`, you can't check out the file if you already have it checked out.	'on' 'off' (default)
'lock'	When set to on, the checkout gets the file, allows you to write to it, and locks the file so that access to the file for others is read only. When set to `off`, the checkout gets a read-only version of the file, allowing another user to check out the file for updating. With `lock` set to `off`, you don't have to check in a file after checking it out.	'on' (default) 'off'
'revision'	Checks out the specified revision of the file.	'version_num'

If you end the MATLAB session, the file remains checked out. You can check in the file from within MATLAB during a later session, or directly from your source control system.

Examples

Check out a File

Typing

```
checkout('/matlab/mymfiles/clock.m')
```

checks out the file `/matlab/mymfiles/clock.m` from the source control system.

Check out Multiple Files

Typing

```
checkout({'/matlab/mymfiles/clock.m',...
'/matlab/mymfiles/calendar.m'})
```

checks out `/matlab/mymfiles/clock.m` and `/matlab/mymfiles/calendar.m` from the source control system.

Force a Checkout, Even If File Is Already Checked out

Typing

```
checkout('/matlab/mymfiles/clock.m','force','on')
```

checks out `/matlab/mymfiles/clock.m` even if `clock.m` is already checked out to you.

Check out Specified Revision of File

Typing

```
checkout('/matlab/mymfiles/clock.m','revision','1.1')
```

checks out revision `1.1` of `clock.m`.

See Also

`checkin`, `cmopts`, `undocheckout`

Purpose Cholesky factorization

Syntax

```
R = chol(X)
[R,p] = chol(X)
```

Description The `chol` function uses only the diagonal and upper triangle of `X`. The lower triangular is assumed to be the (complex conjugate) transpose of the upper. That is, `X` is Hermitian.

`R = chol(X)`, where `X` is positive definite produces an upper triangular `R` so that `R'*R = X`. If `X` is not positive definite, an error message is printed.

`[R,p] = chol(X)`, with two output arguments, never produces an error message. If `X` is positive definite, then `p` is 0 and `R` is the same as above. If `X` is not positive definite, then `p` is a positive integer and `R` is an upper triangular matrix of order `q = p-1` so that `R'*R = X(1:q,1:q)`.

Examples The binomial coefficients arranged in a symmetric array create an interesting positive definite matrix.

```
n = 5;
X = pascal(n)
X =
    1    1    1    1    1
    1    2    3    4    5
    1    3    6   10   15
    1    4   10   20   35
    1    5   15   35   70
```

It is interesting because its Cholesky factor consists of the same coefficients, arranged in an upper triangular matrix.

```
R = chol(X)
R =
    1    1    1    1    1
    0    1    2    3    4
    0    0    1    3    6
    0    0    0    1    4
    0    0    0    0    1
```

Destroy the positive definiteness (and actually make the matrix singular) by subtracting 1 from the last element.

```
X(n,n) = X(n,n)-1

X =
     1     1     1     1     1
     1     2     3     4     5
     1     3     6    10    15
     1     4    10    20    35
     1     5    15    35    69
```

Now an attempt to find the Cholesky factorization fails.

Algorithm

chol uses the the LAPACK subroutines DPOTRF (real) and ZPOTRF (complex).

References

[1] Anderson, E., Z. Bai, C. Bischof, S. Blackford, J. Demmel, J. Dongarra, J. Du Croz, A. Greenbaum, S. Hammarling, A. McKenney, and D. Sorensen, *LAPACK User's Guide* (http://www.netlib.org/lapack/lug/lapack_lug.html), Third Edition, SIAM, Philadelphia, 1999.

See Also

cholinc, cholupdate

Purpose

Sparse incomplete Cholesky and Cholesky-Infinity factorizations

Syntax

```
R = cholinc(X,droptol)
R = cholinc(X,options)
R = cholinc(X,'0')
[R,p] = cholinc(X,'0')
R = cholinc(X,'inf')
```

Description

`cholinc` produces two different kinds of incomplete Cholesky factorizations: the drop tolerance and the 0 level of fill-in factorizations. These factors may be useful as preconditioners for a symmetric positive definite system of linear equations being solved by an iterative method such as `pcg` (Preconditioned Conjugate Gradients). `cholinc` works only for sparse matrices.

`R = cholinc(X,droptol)` performs the incomplete Cholesky factorization of `X`, with drop tolerance `droptol`.

`R = cholinc(X,options)` allows additional options to the incomplete Cholesky factorization. `options` is a structure with up to three fields:

`droptol`	Drop tolerance of the incomplete factorization
`michol`	Modified incomplete Cholesky
`rdiag`	Replace zeros on the diagonal of `R`

Only the fields of interest need to be set.

`droptol` is a non-negative scalar used as the drop tolerance for the incomplete Cholesky factorization. This factorization is computed by performing the incomplete LU factorization with the pivot threshold option set to `0` (which forces diagonal pivoting) and then scaling the rows of the incomplete upper triangular factor, `U`, by the square root of the diagonal entries in that column. Since the nonzero entries `U(i,j)` are bounded below by `droptol*norm(X(:,j))` (see `luinc`), the nonzero entries `R(i,j)` are bounded below by the local drop tolerance `droptol*norm(X(:,j))/R(i,i)`.

Setting `droptol = 0` produces the complete Cholesky factorization, which is the default.

`michol` stands for modified incomplete Cholesky factorization. Its value is either `0` (unmodified, the default) or `1` (modified). This performs the modified incomplete LU factorization of `X` and scales the returned upper triangular factor as described above.

`rdiag` is either `0` or `1`. If it is `1`, any zero diagonal entries of the upper triangular factor R are replaced by the square root of the local drop tolerance in an attempt to avoid a singular factor. The default is `0`.

`R = cholinc(X,'0')` produces the incomplete Cholesky factor of a real sparse matrix that is symmetric and positive definite using no fill-in. The upper triangular `R` has the same sparsity pattern as `triu(X)`, although `R` may be zero in some positions where `X` is nonzero due to cancellation. The lower triangle of `X` is assumed to be the transpose of the upper. Note that the positive definiteness of `X` does not guarantee the existence of a factor with the required sparsity. An error message results if the factorization is not possible. If the factorization is successful, `R'*R` agrees with `X` over its sparsity pattern.

`[R,p] = cholinc(X,'0')` with two output arguments, never produces an error message. If `R` exists, `p` is `0`. If `R` does not exist, then `p` is a positive integer and `R` is an upper triangular matrix of size `q`-by-`n` where `q = p-1`. In this latter case, the sparsity pattern of `R` is that of the `q`-by-`n` upper triangle of `X`. `R'*R` agrees with `X` over the sparsity pattern of its first `q` rows and first `q` columns.

`R = cholinc(X,'inf')` produces the Cholesky-Infinity factorization. This factorization is based on the Cholesky factorization, and additionally handles real positive semi-definite matrices. It may be useful for finding a solution to systems which arise in interior-point methods. When a zero pivot is encountered in the ordinary Cholesky factorization, the diagonal of the Cholesky-Infinity factor is set to `Inf` and the rest of that row is set to `0`. This forces a `0` in the corresponding entry of the solution vector in the associated system of linear equations. In practice, `X` is assumed to be positive semi-definite so even negative pivots are replaced with a value of `Inf`.

Remarks

The incomplete factorizations may be useful as preconditioners for solving large sparse systems of linear equations. A single `0` on the diagonal of the upper triangular factor makes it singular. The incomplete factorization with a drop tolerance prints a warning message if the upper triangular factor has zeros on the diagonal. Similarly, using the `rdiag` option to replace a zero diagonal only gets rid of the symptoms of the problem, but it does not solve it. The preconditioner may not be singular, but it probably is not useful, and a warning message is printed.

The Cholesky-Infinity factorization is meant to be used within interior-point methods. Otherwise, its use is not recommended.

Examples

Example 1.

Start with a symmetric positive definite matrix, S.

```
S = delsq(numgrid('C',15));
```

S is the two-dimensional, five-point discrete negative Lapacian on the grid generated by numgrid('C',15).

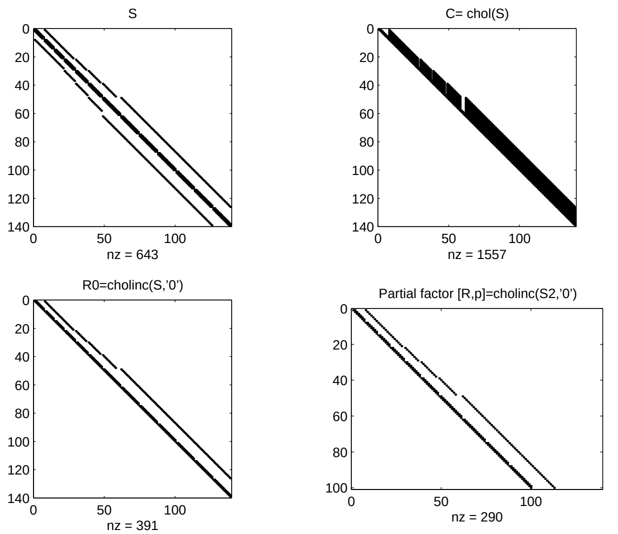
Compute the Cholesky factorization and the incomplete Cholesky factorization of level 0 to compare the fill-in. Make S singular by zeroing out a diagonal entry and compute the (partial) incomplete Cholesky factorization of level 0.

```
C = chol(S);
R0 = cholinc(S,'0');
S2 = S; S2(101,101) = 0;
[R,p] = cholinc(S2,'0');
```

Fill-in occurs within the bands of S in the complete Cholesky factor, but none in the incomplete Cholesky factor. The incomplete factorization of the singular S2 stopped at row p = 101 resulting in a 100-by-139 partial factor.

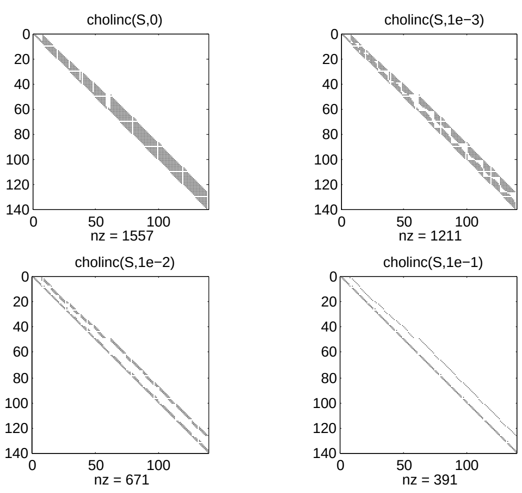
```
D1 = (R0'*R0).*spones(S)-S;
D2 = (R'*R).*spones(S2)-S2;
```

D1 has elements of the order of eps, showing that R0'*R0 agrees with S over its sparsity pattern. D2 has elements of the order of eps over its first 100 rows and first 100 columns, D2(1:100,:) and D2(:,1:100).

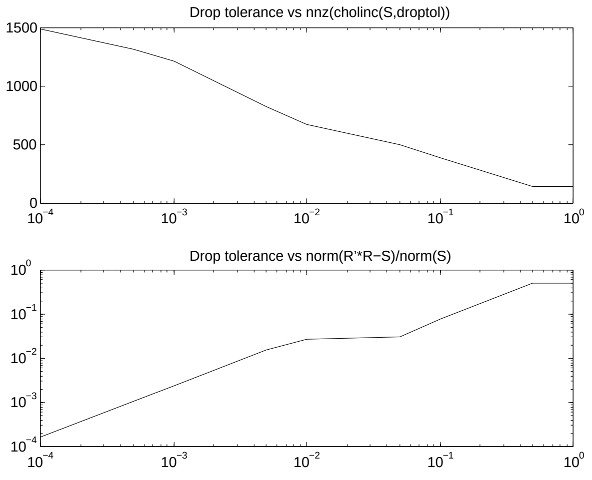


Example 2.

The first subplot below shows that `cholinc(S,0)`, the incomplete Cholesky factor with a drop tolerance of `0`, is the same as the Cholesky factor of `S`. Increasing the drop tolerance increases the sparsity of the incomplete factors, as seen below.



Unfortunately, the sparser factors are poor approximations, as is seen by the plot of drop tolerance versus `norm(R'*R-S,1)/norm(S,1)` in the next figure.



Example 3.

The Hilbert matrices have (i,j) entries 1/(i+j-1) and are theoretically positive definite:

```
H3 = hilb(3)
H3 =
    1.0000    0.5000    0.3333
    0.5000    0.3333    0.2500
    0.3333    0.2500    0.2000

R3 = chol(H3)
R3 =
    1.0000    0.5000    0.3333
         0    0.2887    0.2887
         0         0    0.0745
```

In practice, the Cholesky factorization breaks down for larger matrices:

```
H20 = sparse(hilb(20));
[R,p] = chol(H20);
p =
    14
```

For `hilb(20)`, the Cholesky factorization failed in the computation of row 14 because of a numerically zero pivot. You can use the Cholesky-Infinity factorization to avoid this error. When a zero pivot is encountered, `cholinc` places an `Inf` on the main diagonal, zeros out the rest of the row, and continues with the computation:

```
Rinf = cholinc(H20,'inf');
```

In this case, all subsequent pivots are also too small, so the remainder of the upper triangular factor is:

```
full(Rinf(14:end,14:end))
ans =
   Inf     0     0     0     0     0     0
     0   Inf     0     0     0     0     0
     0     0   Inf     0     0     0     0
     0     0     0   Inf     0     0     0
     0     0     0     0   Inf     0     0
     0     0     0     0     0   Inf     0
     0     0     0     0     0     0   Inf
```

Limitations

`cholinc` works on square sparse matrices only. For `cholinc(X,'0') and` `cholinc(X,'inf')`, `X` must be real.

Algorithm

`R = cholinc(X,droptol)` is obtained from `[L,U] = luinc(X,options)`, where `options.droptol = droptol` and `options.thresh = 0`. The rows of the uppertriangular `U` are scaled by the square root of the diagonal in that row, and this scaled factor becomes `R`.

`R = cholinc(X,options)` is produced in a similar manner, except the `rdiag` option translates into the `udiag` option and the `milu` option takes the value of the `michol` option.

`R = cholinc(X,'0')` is based on the “KJI” variant of the Cholesky factorization. Updates are made only to positions which are nonzero in the upper triangle of `X`.

`R = cholinc(X,'inf')` is based on the algorithm in Zhang [2].

See Also `chol`, `luinc`, `pcg`

References

[1] Saad, Yousef, *Iterative Methods for Sparse Linear Systems*, PWS Publishing Company, 1996. Chapter 10, “Preconditioning Techniques.”

[2] Zhang, Yin, *Solving Large-Scale Linear Programs by Interior-Point Methods Under the MATLAB Environment*, Department of Mathematics and Statistics, University of Maryland Baltimore County, Technical Report TR96-01

cholupdate

Purpose Rank 1 update to Cholesky factorization

Syntax

```
R1 = cholupdate(R,x)
R1 = cholupdate(R,x,'+')
R1 = cholupdate(R,x,'-')
[R1,p] = cholupdate(R,x,'-')
```

Description

`R1 = cholupdate(R,x)` where `R = chol(A)` is the original Cholesky factorization of `A`, returns the upper triangular Cholesky factor of `A + x*x'`, where `x` is a column vector of appropriate length. `cholupdate` uses only the diagonal and upper triangle of `R`. The lower triangle of `R` is ignored.

`R1 = cholupdate(R,x,'+')` is the same as `R1 = cholupdate(R,x)`.

`R1 = cholupdate(R,x,'-')` returns the Cholesky factor of `A - x*x'`. An error message reports when R is not a valid Cholesky factor or when the downdated matrix is not positive definite and so does not have a Cholesky factoriza- tion.

`[R1,p] = cholupdate(R,x,'-')` will not return an error message. If `p` is `0`, `R1` is the Cholesky factor of `A - x*x'`. If `p` is greater than `0`, `R1` is the Cholesky factor of the original `A`. If `p` is `1`, `cholupdate` failed because the downdated matrix is not positive definite. If `p` is `2`, `cholupdate` failed because the upper triangle of `R` was not a valid Cholesky factor.

Remarks `cholupdate` works only for full matrices.

Example

```
A = pascal(4)
A =

     1     1     1     1
     1     2     3     4
     1     3     6    10
     1     4    10    20


R = chol(A)
```

```
R =

     1     1     1     1
     0     1     2     3
     0     0     1     3
     0     0     0     1

x = [0 0 0 1]';
```

This is called a rank one update to `A` since `rank(x*x')` is `1`:

```
A + x*x'
ans =


     1     1     1     1
     1     2     3     4
     1     3     6    10
     1     4    10    21
```

Instead of computing the Cholesky factor with `R1 = chol(A + x*x')`, we can use `cholupdate`:

```
R1 = cholupdate(R,x)
R1 =


    1.0000    1.0000    1.0000    1.0000
         0    1.0000    2.0000    3.0000
         0         0    1.0000    3.0000
         0         0         0    1.4142
```

Next destroy the positive definiteness (and actually make the matrix singular) by subtracting `1` from the last element of `A`. The downdated matrix is:

```
A - x*x'
ans =

     1     1     1     1
     1     2     3     4
     1     3     6    10
     1     4    10    19
```

Compare chol with cholupdate:

```
R1 = chol(A-x*x')
??? Error using ==> chol
Matrix must be positive definite.

R1 = cholupdate(R,x,'-')
??? Error using ==> cholupdate
Downdated matrix must be positive definite.
```

However, subtracting 0.5 from the last element of A produces a positive definite matrix, and we can use cholupdate to compute its Cholesky factor:

```
x = [0 0 0 1/sqrt(2)]';
R1 = cholupdate(R,x,'-')
R1 =
    1.0000    1.0000    1.0000    1.0000
         0    1.0000    2.0000    3.0000
         0         0    1.0000    3.0000
         0         0         0    0.7071
```

Algorithm

cholupdate uses the algorithms from the LINPACK subroutines ZCHUD and ZCHDD. cholupdate is useful since computing the new Cholesky factor from scratch is an $O(N^3)$ algorithm, while simply updating the existing factor in this way is an $O(N^2)$ algorithm.

See Also

chol, qrupdate

References

[1] Dongarra, J.J., J.R. Bunch, C.B. Moler, and G.W. Stewart, *LINPACK Users' Guide*, SIAM, Philadelphia, 1979.

Purpose Shift array circularly

Syntax

```
B = circshift(A,shiftsize)
```

Description `B = circshift(A,shiftsize)` circularly shifts the values in the 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). If it is `0`, the values in that dimension are not shifted.

Example Circularly shift first dimension values down by 1.

```
A = [ 1 2 3;4 5 6; 7 8 9]
A =
     1     2     3
     4     5     6
     7     8     9

B = circshift(A,1)
B =
     7     8     9
     1     2     3
     4     5     6
```

Circularly shift first dimension values down by 1 and second dimension values to the left by 1.

```
B = circshift(A,[1 -1]);
B =
    8     9     7
    2     3     1
    5     6     4
```

See Also `fftshift`, `shiftdim`

cla

Purpose

Clear current axes

Syntax

```
cla
cla reset
```

Description

`cla` deletes from the current axes all graphics objects whose handles are not hidden (i.e., their `HandleVisibility` property is set to `on`).

`cla reset` deletes from the current axes all graphics objects regardless of the setting of their `HandleVisibility` property and resets all axes properties, except `Position` and `Units`, to their default values.

Remarks

The `cla` command behaves the same way when issued on the command line as it does in callback routines – it does not recognize the `HandleVisibility` setting of `callback`. This means that when issued from within a callback routine, `cla` deletes only those objects whose `HandleVisibility` property is set to `on`.

See Also

`clf`, `hold`, `newplot`, `reset`

"Axes Operations" for related functions

Purpose Contour plot elevation labels

Syntax

```
clabel(C,h)
clabel(C,h,v)
clabel(C,h,'manual')

clabel(C)
clabel(C,v)
clabel(C,'manual')
```

Description The `clabel` function adds height labels to a two-dimensional contour plot.

`clabel(C,h)` rotates the labels and inserts them in the contour lines. The function inserts only those labels that fit within the contour, depending on the size of the contour.

`clabel(C,h,v)` creates labels only for those contour levels given in vector `v`, then rotates the labels and inserts them in the contour lines.

`clabel(C,h,'manual')` places contour labels at locations you select with a mouse. Press the left mouse button (the mouse button on a single-button mouse) or the space bar to label a contour at the closest location beneath the center of the cursor. Press the **Return** key while the cursor is within the figure window to terminate labeling. The labels are rotated and inserted in the contour lines.

`clabel(C)` adds labels to the current contour plot using the contour structure `C` output from `contour`. The function labels all contours displayed and randomly selects label positions.

`clabel(C,v)` labels only those contour levels given in vector `v`.

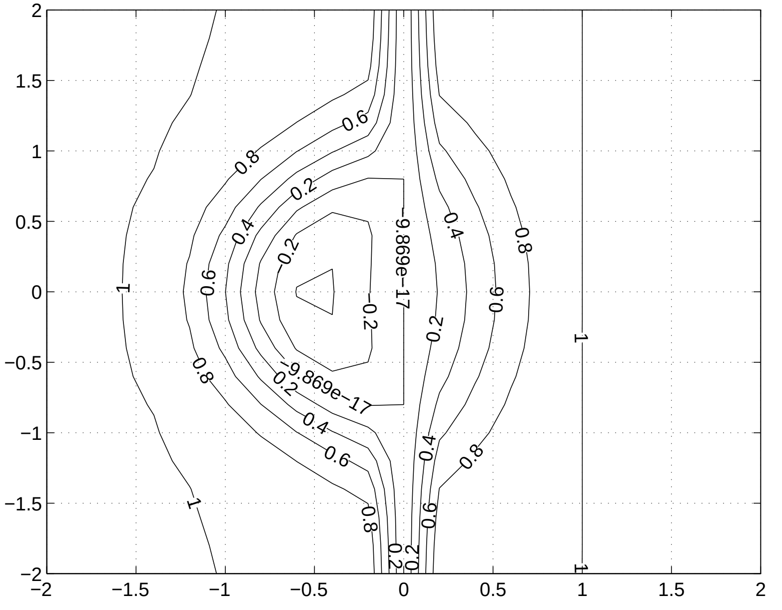
`clabel(C,'manual')` places contour labels at locations you select with a mouse.

Remarks When the syntax includes the argument `h`, this function rotates the labels and inserts them in the contour lines (see Example). Otherwise, the labels are displayed upright and a `'+'` indicates which contour line the label is annotating.

Examples

Generate, draw, and label a simple contour plot.

```
[x,y] = meshgrid(-2:.2:2);
z = x.^exp(-x.^2-y.^2);
[C,h] = contour(x,y,z);
clabel(C,h);
```



See Also

`contour`, `contourc`, `contourf`

"Annotating Plots" for related functions

Drawing Text in a Box for an example that illustrates the use of contour labels

Purpose Create object or return class of object

Syntax

```
str = class(object)
obj = class(s,'class_name')
obj = class(s,'class_name',parent1,parent2...)
obj = class(struct([]),'class_name',parent1,parent2...)
```

Description `str = class(object)` returns a string specifying the class of `object`.

The following table lists the object class names that may be returned. All except the last one are MATLAB classes.

`logical`	Logical array of `true` and `false` values
`char`	Characters array
`int8`	8-bit signed integer array
`uint8`	8-bit unsigned integer array
`int16`	16-bit signed integer array
`uint16`	16-bit unsigned integer array
`int32`	32-bit signed integer array
`uint32`	32-bit unsigned integer array
`int64`	64-bit signed integer array
`uint64`	64-bit unsigned integer array
`single`	Single-precision floating point number array
`double`	Double-precision floating point number array
`cell`	Cell array
`struct`	Structure array
`function handle`	Array of values for calling functions indirectly
`'`*`class_name`*`'`	Custom MATLAB object class or Java class

`obj = class(s,'class_name')` creates an object of MATLAB class `'class_name'` using structure `s` as a template. This syntax is valid only in a function named `class_name.m` in a directory named `@class_name` (where `'class_name'` is the same as the string passed into `class`).

`obj = class(s,'class_name',parent1,parent2,...)` creates an object of MATLAB class `'class_name'` that inherits the methods and fields of the parent objects `parent1`, `parent2`, and so on. Structure `s` is used as a template for the object.

`obj = class(struct([]),'class_name',parent1,parent2,...)` creates an object of MATLAB class `'class_name'` that inherits the methods and fields of the parent objects `parent1`, `parent2`, and so on. Specifying the empty structure, `struct([])`, as the first argument ensures that the object created contains no fields other than those that are inherited from the parent objects.

Examples

To return in `nameStr` the name of the class of Java object `j`

```
nameStr = class(j)
```

To create a user-defined MATLAB object of class `polynom`

```
p = class(p,'polynom')
```

See Also

`inferiorto`, `isa`, `superiorto`

The “MATLAB Classes and Objects” and the “Calling Java from MATLAB” chapters in *Programming and Data Types*.

Purpose Clear Command Window

Graphical Interface As an alternative to the `clc` function, use **Clear Command Window** in the MATLAB desktop **Edit** menu.

Syntax

```
clc
```

Description `clc` clears all input and output from the Command Window display, giving you a "clean screen."

After using `clc`, you cannot use the scroll bar to see the history of functions, but still can use the up arrow to recall statements from the command history.

Examples Use `clc` in an M-file to always display output in the same starting position on the screen.

See Also `clear`, `clf`, `close`, `home`

clear

Purpose

Remove items from workspace, freeing up system memory

Graphical Interface

As an alternative to the `clear` function, use **Clear Workspace** in the MATLAB desktop **Edit** menu, or in the context menu in the Workspace browser.

Syntax

```
clear
clear name
clear name1 name2 name3 ...
clear global name
clear keyword
clear('name1','name2','name3',...)
```

Description

`clear` removes all variables from the workspace. This frees up system memory.

`clear name` removes just the M-file or MEX-file function or variable `name` from the workspace. You can use wildcards (*) to remove items selectively. For example, `clear my*` removes any variables whose names begin with the string `my`. It removes debugging breakpoints in M-files and reinitializes persistent variables, since the breakpoints for a function and persistent variables are cleared whenever the M-file is changed or cleared. If `name` is global, it is removed from the current workspace, but left accessible to any functions declaring it global. If `name` has been locked by `mlock`, it remains in memory.

Use a partial path to distinguish between different overloaded versions of a function. For example, `clear inline/display` clears only the `display` method for `inline` objects, leaving any other implementations in memory.

`clear name1 name2 name3 ...` removes `name1`, `name2`, and `name3` from the workspace.

`clear global name` removes the global variable `name`. If `name` is global, `clear name` removes `name` from the current workspace, but leaves it accessible to any functions declaring it global. Use `clear global name` to completely remove a global variable.

`clear keyword` clears the items indicated by *keyword*.

Keyword	Items Cleared
`all`	Removes all variables, functions, and MEX-files from memory, leaving the workspace empty. Using `clear all` removes debugging breakpoints in M-files and reinitializes persistent variables, since the breakpoints for a function and persistent variables are cleared whenever the M-file is changed or cleared. When issued from the Command Window prompt, also removes the Java packages import list.
`classes`	The same as `clear all`, but also clears MATLAB class definitions. If any objects exist outside the workspace (for example, in user data or persistent variables in a locked M-file), a warning is issued and the class definition is not cleared. Issue a `clear classes` function if the number or names of fields in a class are changed.
`functions`	Clears all the currently compiled M-functions and MEX-functions from memory. Using `clear function` removes debugging breakpoints in the function M-file and reinitializes persistent variables, since the breakpoints for a function and persistent variables are cleared whenever the M-file is changed or cleared.
`global`	Clears all global variables from the workspace.
`import`	Removes the Java packages import list. It can only be issued from the Command Window prompt. It cannot be used in a function.
`variables`	Clears all variables from the workspace.

`clear('name1','name2','name3',...)` is the function form of the syntax. Use this form when the variable name or function name is stored in a string.

Remarks

When you use `clear` in a function, it has the following effect on items in your function and base workspaces:

- `clear name`—If `name` is the name of a function, the function is cleared in both the function workspace and in your base workspace.
- `clear` **`functions`**—All functions are cleared in both the function workspace and in your base workspace.
- `clear` **`global`**—All global variables are cleared in both the function workspace and in your base workspace.
- `clear` **`all`**—All functions, global variables, and classes are cleared in both the function workspace and in your base workspace.

Limitations

`clear` does not affect the amount of memory allocated to the MATLAB process under UNIX.

Examples

Given a workspace containing the following variables

```
  Name        Size           Bytes  Class

  c           3x4             1200  cell array
  frame       1x1                   java.awt.Frame
  gbl1        1x1                8  double array (global)
  gbl2        1x1                8  double array (global)
  xint        1x1                1  int8 array
```

you can clear a single variable, `xint`, by typing

```
clear xint
```

To clear all global variables, type

```
clear global
whos
  Name       Size           Bytes  Class

  c          3x4             1200  cell array
  frame      1x1                   java.awt.Frame
```

To clear all compiled M- and MEX-functions from memory, type `clear functions`. In the case shown below, `clear functions` was unable to clear one M-file function from memory, `testfun`, because the function is locked.

```
clear functions          % Attempt to clear all functions.

inmem
ans =
    'testfun'           % One M-file function remains in memory.

mislocked testfun
ans =
     1                   % This function is locked in memory.
```

Once you unlock the function from memory, you can clear it.

```
munlock testfun
clear functions

inmem
ans =
   Empty cell array: 0-by-1
```

See Also

`clc`, `close`, `import`, `mlock`, `munlock`, `pack`, `persistent`, `who`, `whos`

clear (serial)

Purpose Remove a serial port object from the MATLAB workspace

Syntax

```
clear obj
```

Arguments

`obj` A serial port object or an array of serial port objects.

Description

`clear obj` removes `obj` from the MATLAB workspace.

Remarks

If `obj` is connected to the device and it is cleared from the workspace, then `obj` remains connected to the device. You can restore `obj` to the workspace with the `instrfind` function. A serial port object connected to the device has a `Status` property value of `open`.

To disconnect `obj` from the device, use the `fclose` function. To remove `obj` from memory, use the `delete` function. You should remove invalid serial port objects from the workspace with `clear`.

If you use the `help` command to display help for `clear`, then you need to supply the pathname shown below.

```
help serial/private/clear
```

Example

This example creates the serial port object `s`, copies `s` to a new variable `scopy`, and clears `s` from the MATLAB workspace. `s` is then restored to the workspace with `instrfind` and is shown to be identical to `scopy`.

```
s = serial('COM1');
scopy = s;
clear s
s = instrfind;
isequal(scopy,s)
ans =
     1
```

See Also

Functions

`delete`, `fclose`, `instrfind`, `isvalid`

Properties

`Status`

Purpose

Clear current figure window

Syntax

```
clf
clf reset
```

Description

`clf` deletes from the current figure all graphics objects whose handles are not hidden (i.e., their `HandleVisibility` property is set to `on`).

`clf reset` deletes from the current figure all graphics objects regardless of the setting of their `HandleVisibility` property and resets all figure properties, except `Position`, `Units`, `PaperPosition`, and `PaperUnits` to their default values.

Remarks

The `clf` command behaves the same way when issued on the command line as it does in callback routines – it does not recognize the `HandleVisibility` setting of `callback`. This means that when issued from within a callback routine, `clf` deletes only those objects whose `HandleVisibility` property is set to `on`.

See Also

`cla`, `clc`, `hold`, `reset`

"Figure Windows" for related functions

clipboard

Purpose

Copy and paste strings to and from the system clipboard.

Graphical Interface

As an alternative to `clipboard`, use the Import Wizard. To use the Import Wizard to copy data from the clipboard, select **Paste Special** from the **Edit** menu.

Syntax

```
clipboard('copy',data)
str = clipboard('paste')
data = clipboard('pastespecial')
```

Description

`clipboard('copy', data)` sets the clipboard contents to `data`. If `data` is not a character array, clipboard uses `mat2str` to convert it to a string.

`str = clipboard('paste')` returns the current contents of the clipboard as a string or as an empty string (' '), if the current clipboard content cannot be converted to a string.

`data = clipboard('pastespecial')` returns the current contents of the clipboard as an array using `uiimport`.

Note Requires an active X display on Unix and Java elsewhere.

See Also

`load`, `uiimport`

Purpose

Current time as a date vector

Syntax

```
c = clock
```

Description

`c = clock` returns a 6-element date vector containing the current date and time in decimal form:

```
c = [year month day hour minute seconds]
```

The first five elements are integers. The seconds element is accurate to several digits beyond the decimal point. The statement `fix(clock)` rounds to integer display format.

See Also

`cputime`, `datenum`, `datevec`, `etime`, `tic`, `toc`

Purpose Delete specified figure

Syntax

```
close
close(h)
close name
close all
close all hidden
status = close(...)
```

Description `close` deletes the current figure or the specified figure(s). It optionally returns the status of the close operation.

`close` deletes the current figure (equivalent to `close(gcf)`).

`close(h)` deletes the figure identified by `h`. If `h` is a vector or matrix, `close` deletes all figures identified by `h`.

`close name` deletes the figure with the specified name.

`close all` deletes all figures whose handles are not hidden.

`close all hidden` deletes all figures including those with hidden handles.

`status = close(...)` returns `1` if the specified windows have been deleted and `0` otherwise.

Remarks The `close` function works by evaluating the specified figure's `CloseRequestFcn` property with the statement:

```
eval(get(h,'CloseRequestFcn'))
```

The default `CloseRequestFcn`, `closereq`, deletes the current figure using `delete(get(0,'CurrentFigure'))`. If you specify multiple figure handles, `close` executes each figure's `CloseRequestFcn` in turn. If MATLAB encounters an error that terminates the execution of a `CloseRequestFcn`, the figure is not deleted. Note that using your computer's window manager (i.e., the **Close** menu item) also calls the figure's `CloseRequestFcn`.

If a figure's handle is hidden (i.e., the figure's `HandleVisibility` property is set to `callback` or `off` and the root `ShowHiddenHandles` property is set `on`), you must specify the `hidden` option when trying to access a figure using the `all` option.

To delete all figures unconditionally, use the statements:

```
set(0,'ShowHiddenHandles','on')
delete(get(0,'Children'))
```

The delete function does not execute the figure's `CloseRequestFcn`; it simply deletes the specified figure.

The figure `CloseRequestFcn` allows you to either delay or abort the closing of a figure once the `close` function has been issued. For example, you can display a dialog box to see if the user really wants to delete the figure or save and clean up before closing.

See Also

`delete`, `figure`, `gcf`

The figure `HandleVisibility` property

The root `ShowHiddenHandles` property

"Figure Windows" for related functions

close

Purpose Close Audio Video Interleaved (AVI) file

Syntax

```
aviobj = close(aviobj)
```

Description `aviobj = close(aviobj)` finishes writing and closes the AVI file associated with `aviobj`, which is an AVI file object, created using the `avifile` function.

See Also `avifile`, `addframe`, `movie2avi`

Purpose Default figure close request function

Syntax

```
closereq
```

Description `closereq` delete the current figure.

See Also The figure `CloseRequestFcn` property

"Figure Windows" for related functions

cmopts

Purpose Get name of source control system

Graphical Interface As an alternative to `cmopts`, use preferences. Select **File -> Preferences** in the MATLAB desktop, and then select **General -> Source Control**.

Syntax

```
cmopts
```

Description `cmopts` returns the name of the source control system you selected using preferences, which is one of the following:

```
clearcase
customverctrl
pvcs
rcs
sourcesafe
```

If you have not selected a source control system, `cmopts` returns

```
none
```

Specifying a Source Control System

To specify the source control system:

1. From the MATLAB Editor window or from a Simulink or Stateflow model window, select **File -> Preferences**.

   The **Preferences** dialog box opens.

2. In the left pane, click the **+** for **General**, and then select **Source Control**.

   The currently selected system is shown.

3. Select the system you want to use from the **Source control system** list.
4. Click **OK**.

For more information, see source control preferences.

Examples Type `cmopts` and MATLAB returns `rcs`, meaning the source control system specified in preferences is RCS.

See Also `checkin`, `checkout`, `customverctrl`

Purpose

Column approximate minimum degree permutation

Syntax

```
p = colamd(S)
p = colamd(S,knobs)
[p,stats] = colamd(S)
[p,stats] = colamd(S,knobs)
```

Description

`p = colamd(S)` returns the column approximate minimum degree permutation vector for the sparse matrix `S`. For a non-symmetric matrix `S`, `S(:,p)` tends to have sparser LU factors than `S`. The Cholesky factorization of `S(:,p)' * S(:,p)` also tends to be sparser than that of `S'*S`.

`knobs` is a two-element vector. If S is `m`-by-`n`, then rows with more than `(knobs(1))*n` entries are ignored. Columns with more than `(knobs(2))*m` entries are removed prior to ordering, and ordered last in the output permutation `p`. If the `knobs` parameter is not present, then `knobs(1)` = `knobs(2) = spparms('wh_frac')`.

`stats` is an optional vector that provides data about the ordering and the validity of the matrix `S`.

`stats(1)`	Number of dense or empty rows ignored by `colamd`
`stats(2)`	Number of dense or empty columns ignored by `colamd`
`stats(3)`	Number of garbage collections performed on the internal data structure used by `colamd` (roughly of size `2.2*nnz(S) + 4*m + 7*n` integers)
`stats(4)`	`0` if the matrix is valid, or `1` if invalid
`stats(5)`	Rightmost column index that is unsorted or contains duplicate entries, or `0` if no such column exists
`stats(6)`	Last seen duplicate or out-of-order row index in the column index given by `stats(5)`, or `0` if no such row index exists
`stats(7)`	Number of duplicate and out-of-order row indices

Although, MATLAB built-in functions generate valid sparse matrices, a user may construct an invalid sparse matrix using the MATLAB C or Fortran APIs and pass it to `colamd`. For this reason, `colamd` verifies that `S` is valid:

- If a row index appears two or more times in the same column, `colamd` ignores the duplicate entries, continues processing, and provides information about the duplicate entries in `stats(4:7)`.
- If row indices in a column are out of order, `colamd` sorts each column of its internal copy of the matrix `S` (but does not repair the input matrix `S`), continues processing, and provides information about the out-of-order entries in `stats(4:7)`.
- If `S` is invalid in any other way, `colamd` cannot continue. It prints an error message, and returns no output arguments (`p` or `stats`) .

The ordering is followed by a column elimination tree post-ordering.

Note `colamd` tends to be faster than `colmmd` and tends to return a better ordering.

See Also

`colmmd`, `colperm`, `spparms`, `symamd`, `symmmd`, `symrcm`

References

[1] The authors of the code for `colamd` are Stefan I. Larimore and Timothy A. Davis (`davis@cise.ufl.edu`), University of Florida. The algorithm was developed in collaboration with John Gilbert, Xerox PARC, and Esmond Ng, Oak Ridge National Laboratory. Sparse Matrix Algorithms Research at the University of Florida: `http://www.cise.ufl.edu/research/sparse/`

Purpose Sparse column minimum degree permutation

Syntax

```
p = colmmd(S)
```

Description

p = colmmd(S) returns the column minimum degree permutation vector for the sparse matrix S. For a nonsymmetric matrix S, this is a column permutation p such that S(:,p) tends to have sparser LU factors than S.

The colmmd permutation is automatically used by \ and / for the solution of nonsymmetric and symmetric indefinite sparse linear systems.

Use spparms to change some options and parameters associated with heuristics in the algorithm.

Algorithm

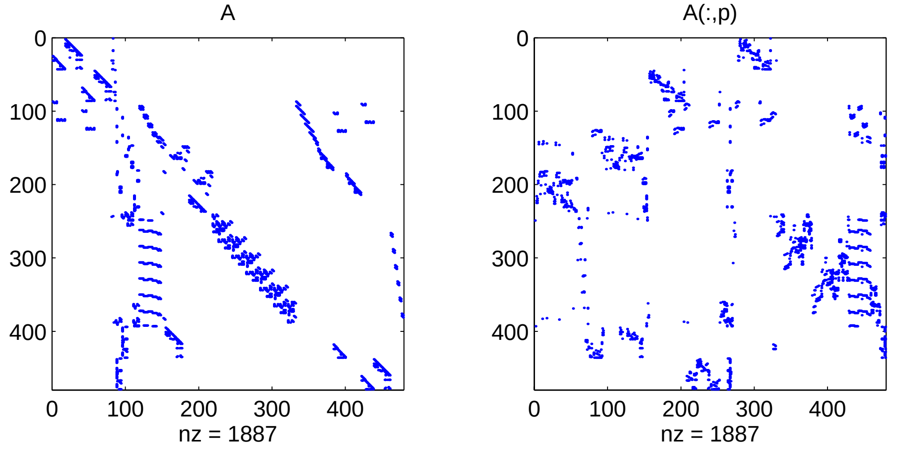
The minimum degree algorithm for symmetric matrices is described in the review paper by George and Liu [1]. For nonsymmetric matrices, the MATLAB minimum degree algorithm is new and is described in the paper by Gilbert, Moler, and Schreiber [2]. It is roughly like symmetric minimum degree for A'*A, but does not actually form A'*A.

Each stage of the algorithm chooses a vertex in the graph of A'*A of lowest degree (that is, a column of A having nonzero elements in common with the fewest other columns), eliminates that vertex, and updates the remainder of the graph by adding fill (that is, merging rows). If the input matrix S is of size m-by-n, the columns are all eliminated and the permutation is complete after n stages. To speed up the process, several heuristics are used to carry out multiple stages simultaneously.

Examples

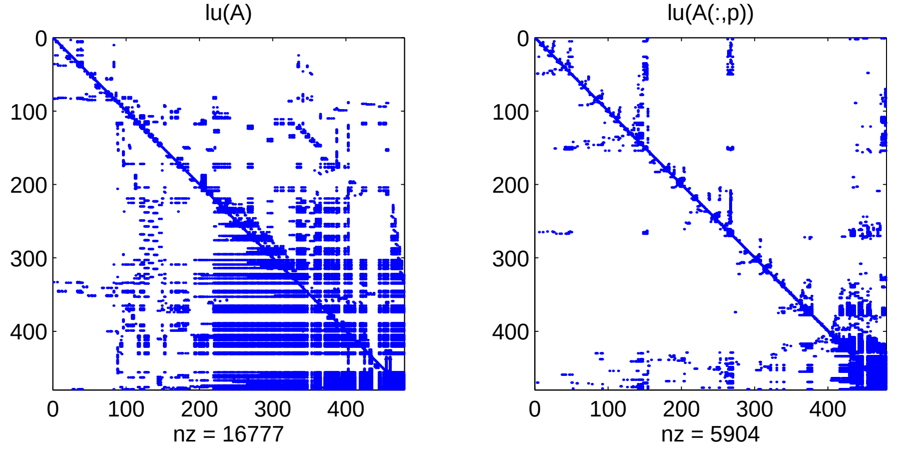
The Harwell-Boeing collection of sparse matrices and the MATLAB demos directory include a test matrix WEST0479. It is a matrix of order 479 resulting from a model due to Westerberg of an eight-stage chemical distillation column. The spy plot shows evidence of the eight stages. The colmmd ordering scrambles this structure.

```
load west0479
A = west0479;
p = colmmd(A);
spy(A)
spy(A(:,p))
```



Comparing the spy plot of the LU factorization of the original matrix with that of the reordered matrix shows that minimum degree reduces the time and storage requirements by better than a factor of 2.8. The nonzero counts are 16777 and 5904, respectively.

```
spy(lu(A))
spy(lu(A(:,p)))
```



See Also

`colamd`, `colperm`, `lu`, `spparms`, `symamd`, `symmmd`, `symrcm`

The arithmetic operator `\`

References

[1] George, Alan and Liu, Joseph, “The Evolution of the Minimum Degree Ordering Algorithm,” *SIAM Review*, 1989, 31:1-19.

[2] Gilbert, John R., Cleve Moler, and Robert Schreiber, “Sparse Matrices in MATLAB: Design and Implementation,” *SIAM Journal on Matrix Analysis and Applications 13*, 1992, pp. 333-356.

Purpose Display colorbar showing the color scale

Syntax

```
colorbar
colorbar('vert')
colorbar('horiz')
colorbar(h)
h = colorbar(...)
colorbar(...,'peer',axes_handle)
```

Description The `colorbar` function displays the current colormap in the current figure and resizes the current axes to accommodate the colorbar.

`colorbar` updates the most recently created colorbar or, when the current axes does not have a colorbar, `colorbar` adds a new vertical colorbar.

`colorbar('vert')` adds a vertical colorbar to the current axes.

`colorbar('horiz')` adds a horizontal colorbar to the current axes.

`colorbar(h)` uses the axes `h` to create the colorbar. The colorbar is horizontal if the width of the axes is greater than its height, as determined by the axes `Position` property.

`h = colorbar(...)` returns a handle to the colorbar, which is an axes graphics object.

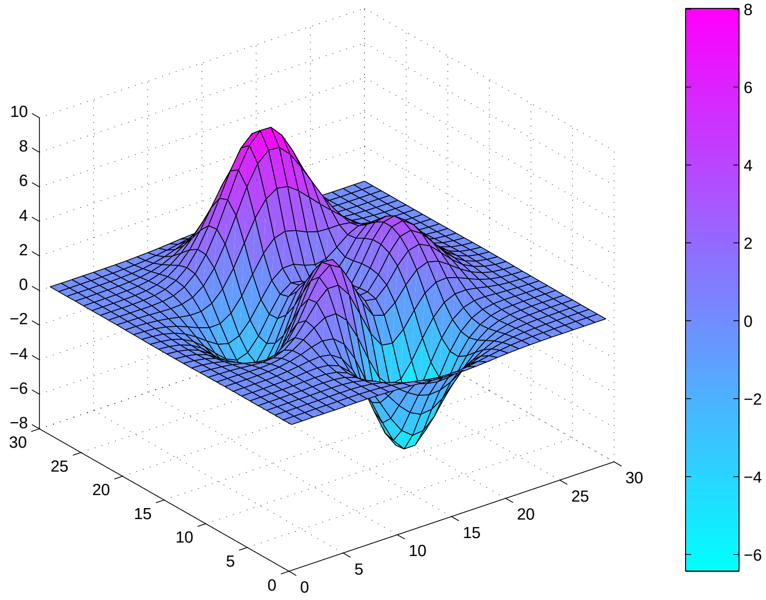
`colorbar(...,'peer',axes_handle)` creates a colorbar associated with the axes `axes_handle` instead of the current axes.

Remarks `colorbar` works with two-dimensional and three-dimensional plots.

Examples Display a colorbar beside the axes.

```
surf(peaks(30))
colormap cool
```

```
colorbar
```



See Also `colormap`

"Color Operations" for related functions

colordef

Purpose

Sets default property values to display different color schemes

Syntax

```
colordef white
colordef black
colordef none
colordef(fig,color_option)
h = colordef('new',color_option)
```

Description

`colordef` enables you to select either a white or black background for graphics display. It sets axis lines and labels to show up against the background color.

`colordef white` sets the axis background color to white, the axis lines and labels to black, and the figure background color to light gray.

`colordef black` sets the axis background color to black, the axis lines and labels to white, and the figure background color to dark gray.

`colordef none` sets the figure coloring to that used by MATLAB Version 4 (essentially a black background).

`colordef(fig,color_option)` sets the color scheme of the figure identified by the handle `fig` to the color option `'white'`, `'black'`, or `'none'`.

`h = colordef('new',color_option)` returns the handle to a new figure created with the specified color options (i.e., `'white'`, `'black'`, or `'none'`).

Remarks

`colordef` affects only subsequently drawn figures, not those currently on the display. This is because `colordef` works by setting default property values (on the root or figure level). You can list the currently set default values on the root level with the statement:

```
get(0,'defaults')
```

You can remove all default values using the `reset` command:

```
reset(0)
```

See the `get` and `reset` references pages for more information.

See Also

`whitebg`

“Color Operations” for related functions

colormap

Purpose

Set and get the current colormap

Syntax

```
colormap(map)
colormap('default')
cmap = colormap
```

Description

A colormap is an m-by-3 matrix of real numbers between 0.0 and 1.0. Each row is an RGB vector that defines one color. The k^{th} row of the colormap defines the k-th color, where `map(k,:) = [r(k) g(k) b(k)]`) specifies the intensity of red, green, and blue.

`colormap(map)` sets the colormap to the matrix `map`. If any values in `map` are outside the interval [0 1], MATLAB returns the error: `Colormap must have values in [0,1]`.

`colormap('default')` sets the current colormap to the default colormap.

`cmap = colormap;` retrieves the current colormap. The values returned are in the interval [0 1].

Specifying Colormaps

M-files in the `color` directory generate a number of colormaps. Each M-file accepts the colormap size as an argument. For example,

```
colormap(hsv(128))
```

creates an `hsv` colormap with 128 colors. If you do not specify a size, MATLAB creates a colormap the same size as the current colormap.

Supported Colormaps

MATLAB supports a number of colormaps.

- `autumn` varies smoothly from red, through orange, to yellow.
- `bone` is a grayscale colormap with a higher value for the blue component. This colormap is useful for adding an “electronic” look to grayscale images.
- `colorcube` contains as many regularly spaced colors in RGB colorspace as possible, while attempting to provide more steps of gray, pure red, pure green, and pure blue.

- `cool` consists of colors that are shades of cyan and magenta. It varies smoothly from cyan to magenta.
- `copper` varies smoothly from black to bright copper.
- `flag` consists of the colors red, white, blue, and black. This colormap completely changes color with each index increment.
- `gray` returns a linear grayscale colormap.
- `hot` varies smoothly from black, through shades of red, orange, and yellow, to white.
- `hsv` varies the hue component of the hue-saturation-value color model. The colors begin with red, pass through yellow, green, cyan, blue, magenta, and return to red. The colormap is particularly appropriate for displaying periodic functions. `hsv(m)` is the same as `hsv2rgb([h ones(m,2)])` where `h` is the linear ramp, `h = (0:m–1)'/m`.
- `jet` ranges from blue to red, and passes through the colors cyan, yellow, and orange. It is a variation of the `hsv` colormap. The `jet` colormap is associated with an astrophysical fluid jet simulation from the National Center for Supercomputer Applications. See the "Examples" section.
- `lines` produces a colormap of colors specified by the axes `ColorOrder` property and a shade of gray.
- `pink` contains pastel shades of pink. The pink colormap provides sepia tone colorization of grayscale photographs.
- `prism` repeats the six colors red, orange, yellow, green, blue, and violet.
- `spring` consists of colors that are shades of magenta and yellow.
- `summer` consists of colors that are shades of green and yellow.
- `white` is an all white monochrome colormap.
- `winter` consists of colors that are shades of blue and green.

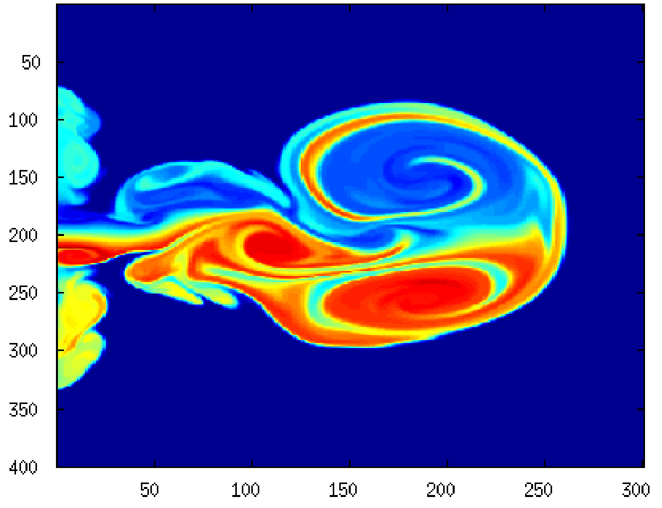
Examples

The images and colormaps demo, `imagedemo`, provides an introduction to colormaps. Select **Color Spiral** from the menu. This uses the `pcolor` function to display a 16-by-16 matrix whose elements vary from 0 to 255 in a rectilinear spiral. The `hsv` colormap starts with red in the center, then passes through yellow, green, cyan, blue, and magenta before returning to red at the outside end of the spiral. Selecting **Colormap Menu** gives access to a number of other colormaps.

The `rgbplot` function plots colormap values. Try `rgbplot(hsv)`, `rgbplot(gray)`, and `rgbplot(hot)`.

The following commands display the `flujet` data using the `jet` colormap.

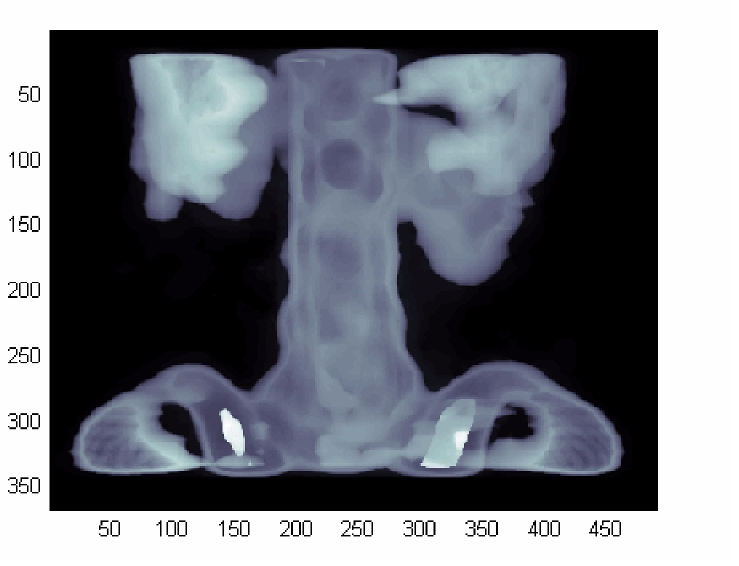
```
load flujet
image(X)
colormap(jet)
```



The `demos` directory contains a CAT scan image of a human spine. To view the image, type the following commands:

```
load spine
image(X)
```

```
colormap bone
```



Algorithm

Each figure has its own `Colormap` property. `colormap` is an M-file that sets and gets this property.

See Also

`brighten`, `caxis`, `colormapeditor`, `colorbar`, `contrast`, `hsv2rgb`, `pcolor`, `rgb2hsv`, `rgbplot`

The `Colormap` property of figure graphics objects.

"Color Operations" for related functions

Coloring Mesh and Surface Plots for more information about colormaps and other coloring methods.

colormapeditor

Purpose

Start colormap editor

Syntax

```
colormapeditor
```

Description

`colormapeditor` displays the current figure's colormap as a strip of rectangular cells in the colormap editor. Node pointers are colored cells below the colormap strip that indicate points in the colormap where the rate of the variation of R, G, and B values change. You can also work in the HSV colorspace by setting the **Interpolating Colorspace** selector to HSV.

You can also start the colormap editor by selecting **Colormap** from the **Edit** menu.

Node Pointer Operations

You can select and move node pointers to change a range of colors in the colormap. The color of a node pointer remains constant as you move it, but the colormap changes by linearly interpolating the RGB values between nodes.

Change the color at a node by double-clicking the node pointer. MATLAB displays a color picker from which you can select a new color. After you select a new color at a node, MATLAB reinterpolates the colors in between nodes.

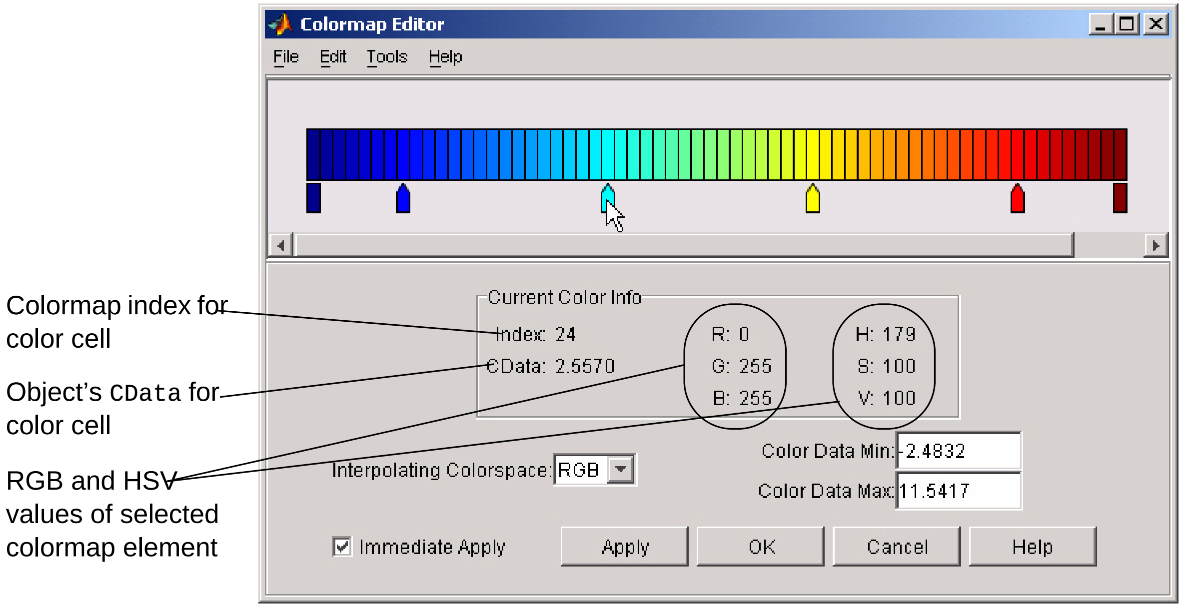
Operation	How to Perform
Add a node	Click below the corresponding cell in the colormap strip
Select a node	Left-click on the node
Select multiple nodes	Adjacent: left-click on first node, **Shift+click** on the last node Nonadjacent: left-click on first node, **Ctrl+click** on subsequent nodes
Move a node	Select and drag with the mouse or select and use the left and right arrow keys.

Operation	How to Perform
Move multiple nodes	Select multiple nodes and use the left and right arrow keys to move nodes as a group. Movement stops when one of the selected nodes hits an unselected node or an end node.
Delete a node	Select the node and then press the **Delete** key, or select **Delete** from the **Edit** menu, or type **Ctrl+x**.
Delete multiple nodes	Select the nodes and then press the **Delete** key, or select **Delete** from the **Edit** menu, or type **Ctrl+x**.
Display color picker for a node	Double click on the node pointer.

Current Color Info

When you put the mouse over a color cell or node pointer, the colormap editor displays the following information about that colormap element:

- The element's index in the colormap
- The value from the graphics object color data that is mapped to the node's color (i.e., data from the `CData` property of any image, patch, or surface objects in the figure)
- The color's RGB and HSV color value



Interpolating Colorspace

The colorspace determines what values are used to calculate the colors of cells between nodes. For example, in the RGB colorspace, internode colors are calculated by linearly interpolating the red, green, and blue intensity values from one node to the next. Switching to the HSV colorspace causes the colormap editor to recalculate the colors between nodes using the hue, saturation, and value components of the color definition.

Note that when you switch from one colorspace to another, the color editor preserves the number, color, and location of the node pointers, which can cause the colormap to change.

Interpolating in HSV: Since hue is conceptually mapped about a color circle, the interpolation between hue values can be ambiguous. To minimize this ambiguity, the interpolation uses the shortest distance around the circle. For example, interpolating between two nodes, one with at hue of 2 (slightly orange red) and another with a hue of 356 (slightly magenta red), does not result in hues 3,4,5...353,354,355 (orange/red-yellow-green-cyan-blue-magenta/red).

Taking the shortest distance around the circle gives 357,358,1,2 (orange/red-red-magenta/red).

Color Data Min and Max

The **Color Data Min** and **Color Data Max** text fields enable you to specify values for the axes `CLim` property. These values change the mapping of object color data (the `CData` property of images, patches, and surfaces) to the colormap. See Axes Color Limits — The Clim Property for discussion and examples of how to use this property.

Examples

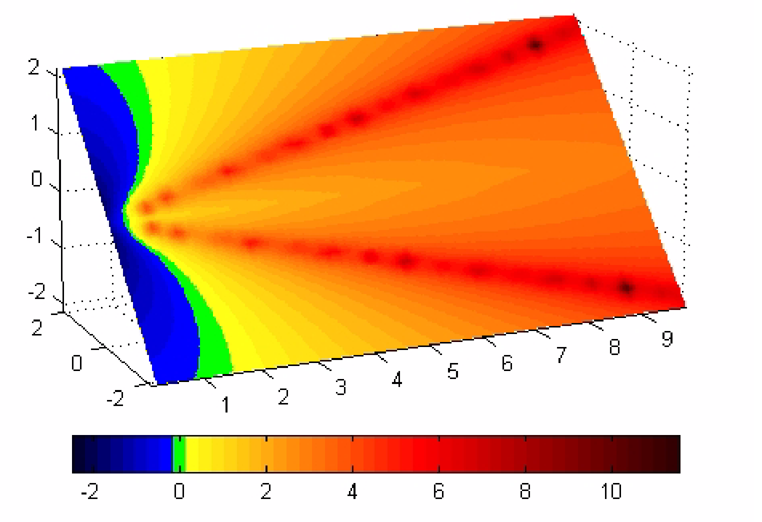
This example modifies a default MATLAB colormap so that ranges of data values are displayed in specific ranges of color. The graph is a slice plane illustrating a cross section of fluid flow through a jet nozzle. See the `slice` reference page for more information on this type of graph.

Example Objectives

The objectives are as follows:

- Regions of flow from left to right (positive data) are mapped to colors from yellow through orange to dark red. Yellow is slowest and dark red is the fastest moving fluid.
- Regions that have a speed close to zero are colored green.
- Regions where the fluid is actually moving right to left (negative data) are shades of blue (darker blue is faster).

The following picture shows the desired coloring of the slice plane. The colorbar shows the data to color mapping.

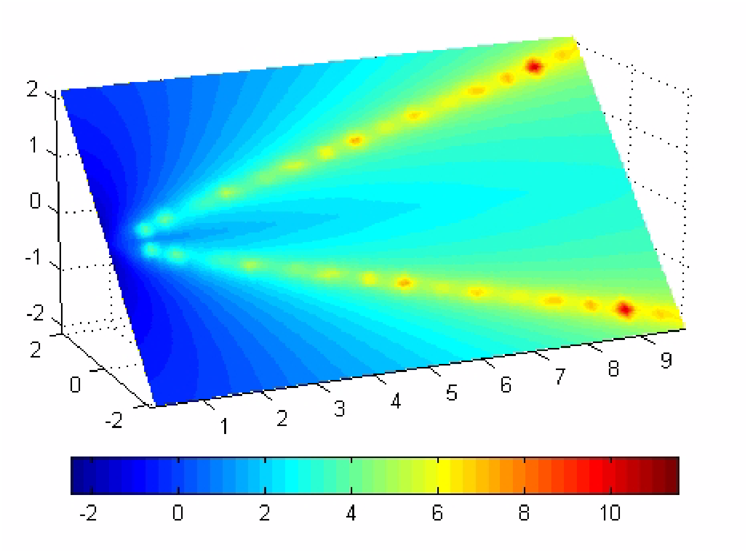


Running the Example

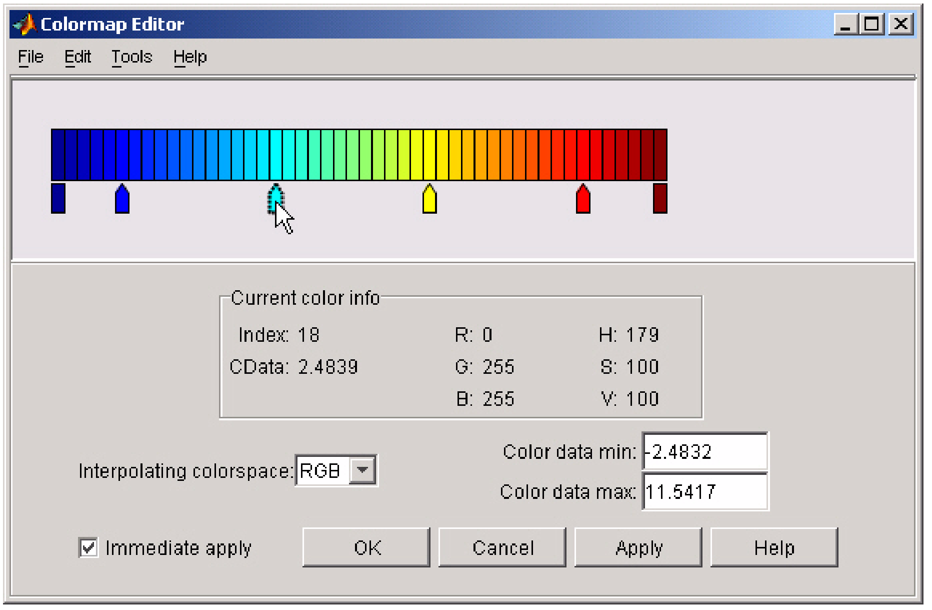
Note If you are viewing this documentation in the MATLAB help browser, you can display the graph used in this example by running this M-file from the MATLAB editor (select **Run** from the **Debug** menu).

Click Run Demo if you want to run a demonstration of the example.

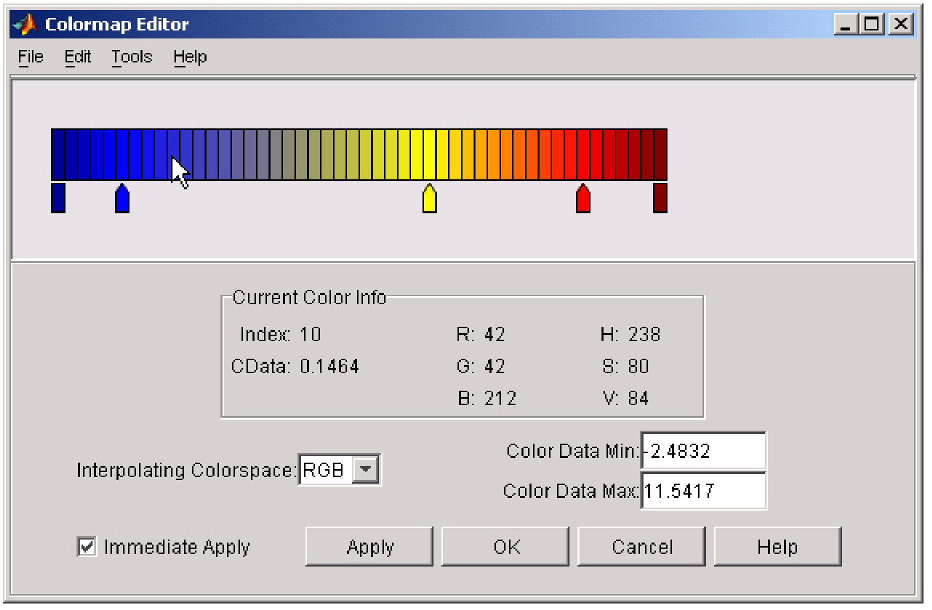
Initially, the default colormap (`jet`) colored the slice plane, as illustrated in the following picture. Note that this example uses a colormap that is 48 elements to display wider bands of color (the default is 64 elements).



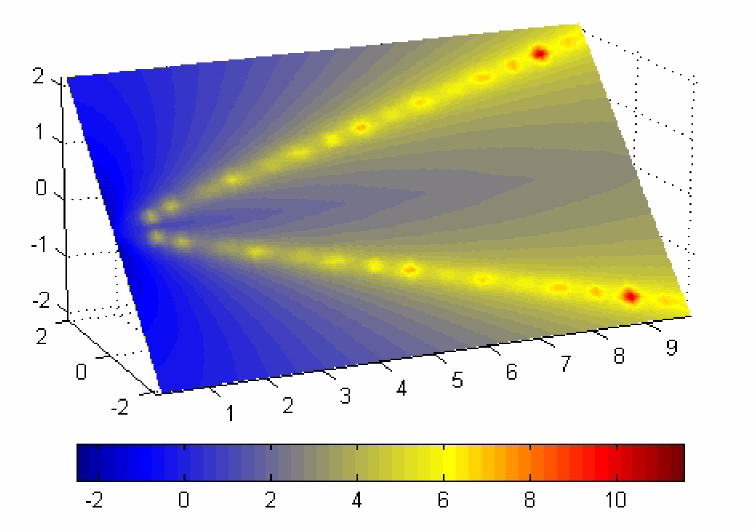
1 Start the colormap editor using the `colormapeditor` command. The color map editor displays the current figure's colormap, as shown in the following picture.



2 Since we want the regions of left-to-right flow (positive speed) to range from yellow to dark red, we can delete the cyan node pointer. To do this, first select it by clicking with the left mouse button and press **Delete**. The colormap now looks like this.

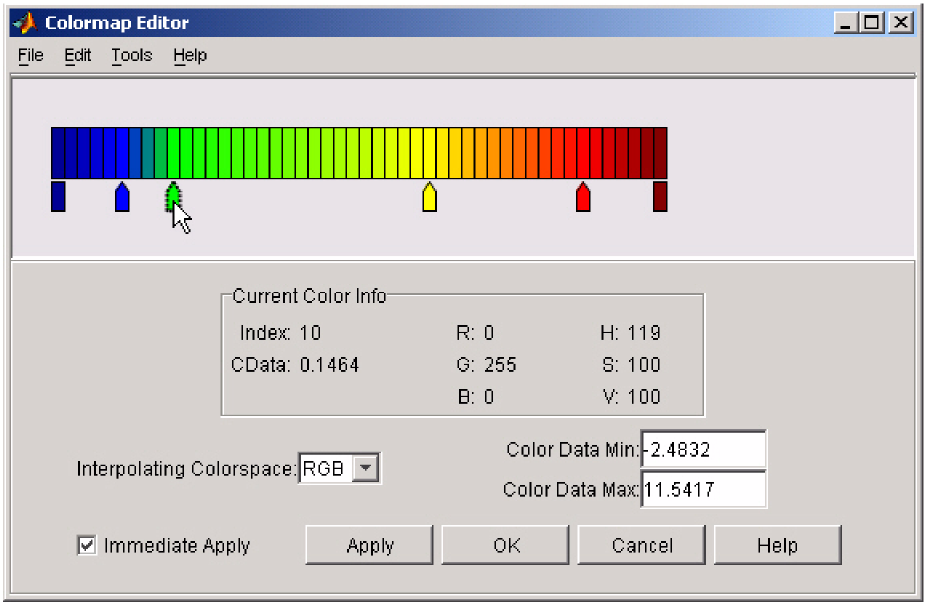


The **Immediate Apply** box is checked so the graph displays the results of the changes made to the colormap.

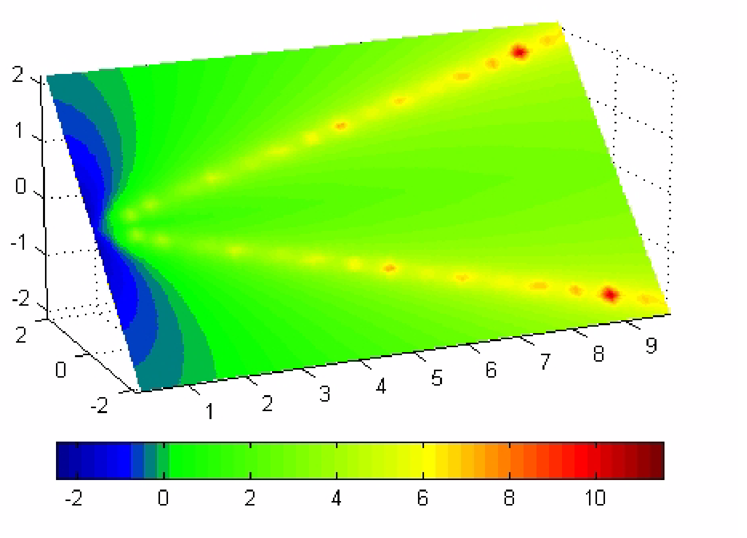


3 We want the fluid speed values around zero to stand out, so we need to find the color cell where the negative-to-positive transition occurs. Dragging the cursor over the color strip enables you to read the data values in the **Current Color Info** panel.

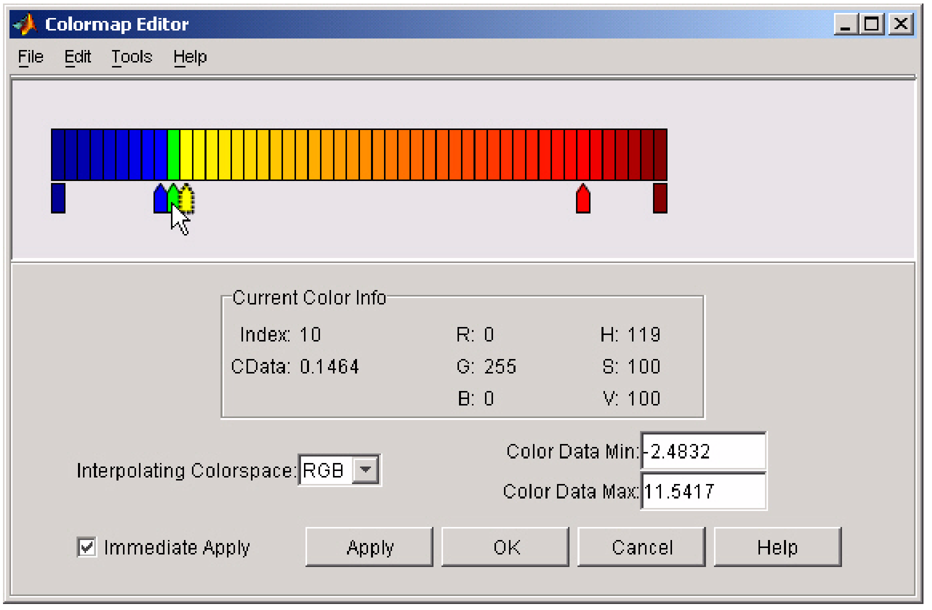
In this case, cell 10 is the first positive value, so we click below that cell and create a node pointer. Double-clicking on the node pointer displays the color picker. Set the color of this node to green.



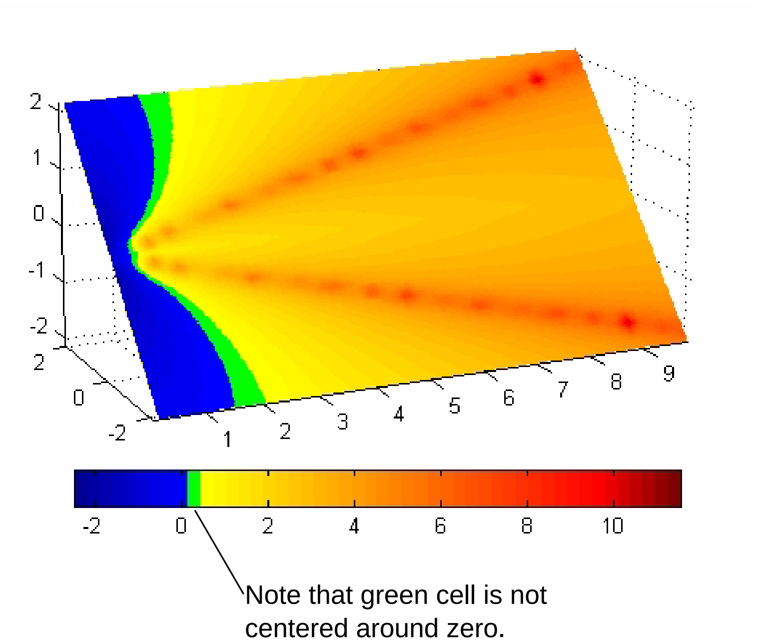
The graph continues to update to the modified colormap.



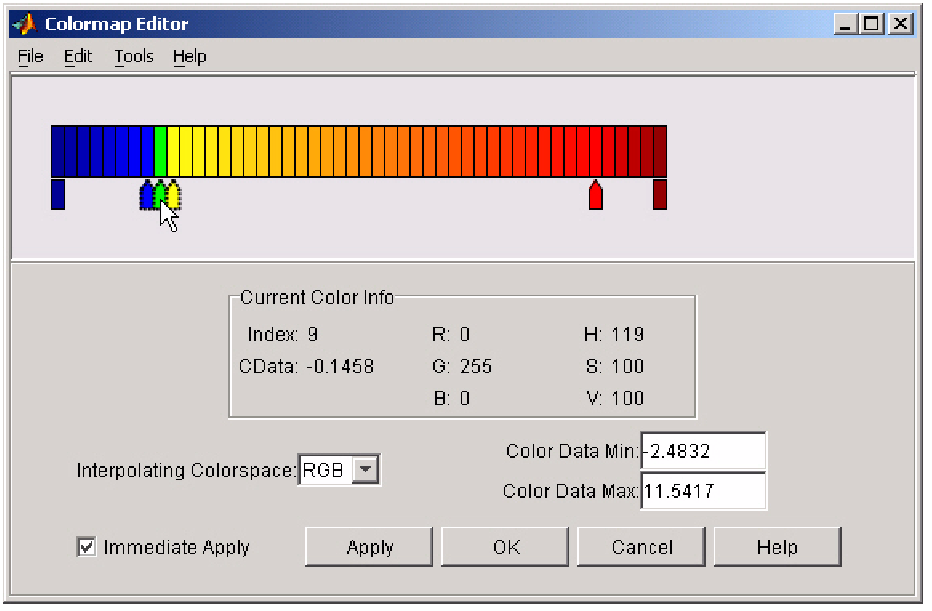
4 In the current state, the colormap colors are interpolated from the green node to the yellowish node about 20 cells away. We actually want only the single cell that is centered around zero to be colored green. To limit the color green to one cell, move the blue and yellow node pointers next to the green pointer.



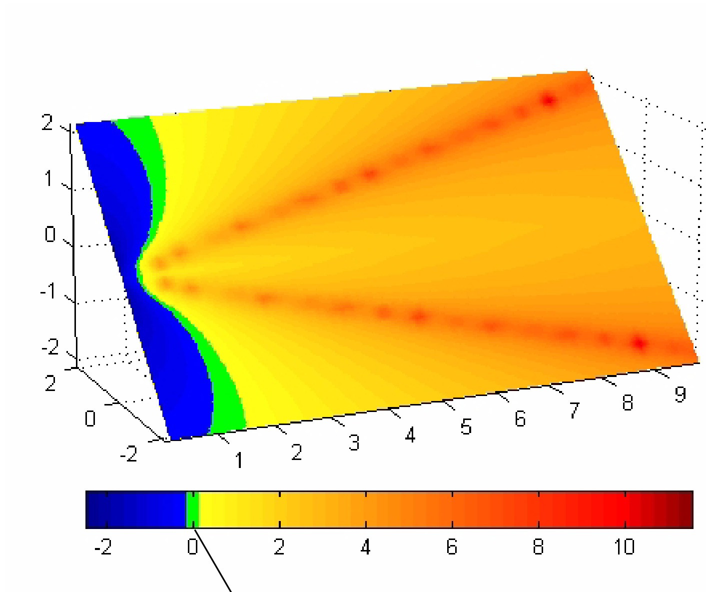
5 Before making further adjustments to the colormap, we need to move the green cell so that it is centered around zero. Use the colorbar to locate the green cell.



To recenter the green cell around zero, select the blue, green, and yellow node pointers (left-click on blue, **Shift+click** on yellow) and move them as a group using the left arrow key. Watch the colorbar in the figure window to see when the green color is centered around zero.

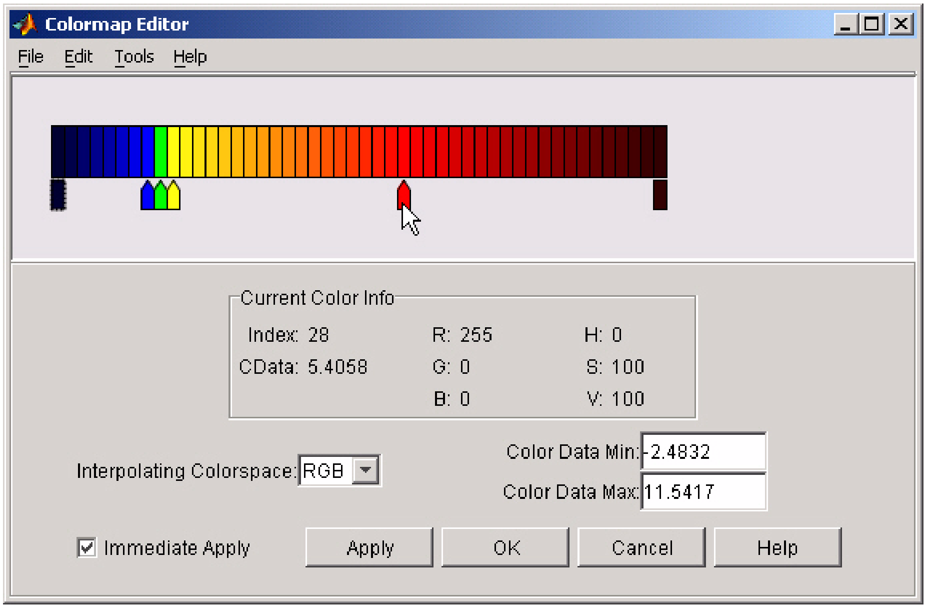


The slice plane now has the desired range of colors for negative, zero, and positive data.



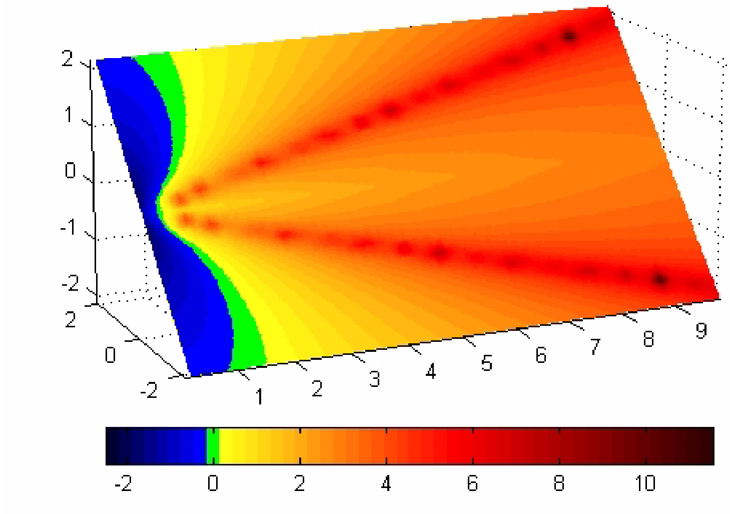
Green cell is now centered around zero.

6 Increase the orange-red coloring in the slice by moving the red node pointer towards the yellow node.



7 Darken the end points to bring out more detail in the extremes of the data. Double-click on the end nodes to display the color picker. Set the red end point to the RGB value [50 0 0] and set the blue end point to the RGB value [0 0 50].

The slice plane coloring now matches the example objectives.



See Also `colormap`

Color Operations for related functions.

ColorSpec

Purpose Color specification

Description `ColorSpec` is not a command; it refers to the three ways in which you specify color in MATLAB:

- RGB triple
- Short name
- Long name

The short names and long names are MATLAB strings that specify one of eight predefined colors. The RGB triple is a three-element row vector whose elements specify the intensities of the red, green, and blue components of the color; the intensities must be in the range [0 1]. The following table lists the predefined colors and their RGB equivalents.

RGB Value	Short Name	Long Name
`[1 1 0]`	`y`	`yellow`
`[1 0 1]`	`m`	`magenta`
`[0 1 1]`	`c`	`cyan`
`[1 0 0]`	`r`	`red`
`[0 1 0]`	`g`	`green`
`[0 0 1]`	`b`	`blue`
`[1 1 1]`	`w`	`white`
`[0 0 0]`	`k`	`black`

Remarks The eight predefined colors and any colors you specify as RGB values are not part of a figure's colormap, nor are they affected by changes to the figure's colormap. They are referred to as *fixed* colors, as opposed to *colormap* colors.

Examples To change the background color of a figure to green, specify the color with a short name, a long name, or an RGB triple. These statements generate equivalent results:

```
whitebg('g')
```

```
whitebg('green')
whitebg([0 1 0]);
```

You can use `ColorSpec` anywhere you need to define a color. For example, this statement changes the figure background color to pink:

```
set(gcf,'Color',[1,0.4,0.6])
```

See Also

`bar`, `bar3`, `colordef`, `colormap`, `fill`, `fill3`, `whitebg`

"Color Operations" for related functions

colperm

Purpose Sparse column permutation based on nonzero count

Syntax

```
j = colperm(S)
```

Description `j = colperm(S)` generates a permutation vector `j` such that the columns of `S(:,j)` are ordered according to increasing count of nonzero entries. This is sometimes useful as a preordering for LU factorization; in this case use `lu(S(:,j))`.

If `S` is symmetric, then `j = colperm(S)` generates a permutation `j` so that both the rows and columns of `S(j,j)` are ordered according to increasing count of nonzero entries. If `S` is positive definite, this is sometimes useful as a preordering for Cholesky factorization; in this case use `chol(S(j,j))`.

Algorithm The algorithm involves a sort on the counts of nonzeros in each column.

Examples The n-by-n *arrowhead* matrix

```
A = [ones(1,n); ones(n-1,1) speye(n-1,n-1)]
```

has a full first row and column. Its LU factorization, `lu(A)`, is almost completely full. The statement

```
j = colperm(A)
```

returns `j = [2:n 1]`. So `A(j,j)` sends the full row and column to the bottom and the rear, and `lu(A(j,j))` has the same nonzero structure as `A` itself.

On the other hand, the Bucky ball example,

```
B = bucky
```

has exactly three nonzero elements in each row and column, so `j = colperm(B)` is the identity permutation and is no help at all for reducing fill-in with subsequent factorizations.

See Also `chol`, `colamd`, `colmmd`, `lu`, `spparms`, `symamd`, `symmmd`, `symrcm`

Purpose Two-dimensional comet plot

Syntax

```
comet(y)
comet(x,y)
comet(x,y,p)
```

Description A comet plot is an animated graph in which a circle (the comet *head*) traces the data points on the screen. The comet *body* is a trailing segment that follows the head. The *tail* is a solid line that traces the entire function.

`comet(y)` displays a comet plot of the vector `y`.

`comet(x,y)` displays a comet plot of vector `y` versus vector `x`.

`comet(x,y,p)` specifies a comet body of length `p*length(y)`. `p` defaults to `0.1`.

Remarks Note that the trace left by `comet` is created by using an `EraseMode` of none, which means you cannot print the plot (you get only the comet head) and it disappears if you cause a redraw (e.g., by resizing the window).

Examples Create a simple comet plot:

```
t = 0:.01:2*pi;
x = cos(2*t).*(cos(t).^2);
y = sin(2*t).*(sin(t).^2);
comet(x,y);
```

See Also `comet3`

"Direction and Velocity Plots" for related functions

comet3

Purpose Three-dimensional comet plot

Syntax

```
comet3(z)
comet3(x,y,z)
comet3(x,y,z,p)
```

Description A comet plot is an animated graph in which a circle (the comet *head*) traces the data points on the screen. The comet *body* is a trailing segment that follows the head. The *tail* is a solid line that traces the entire function.

`comet3(z)` displays a three-dimensional comet plot of the vector `z`.

`comet3(x,y,z)` displays a comet plot of the curve through the points `[x(i),y(i),z(i)]`.

`comet3(x,y,z,p)` specifies a comet body of length `p*length(y)`.

Remarks Note that the trace left by `comet3` is created by using an `EraseMode` of `none`, which means you cannot print the plot (you get only the comet head) and it disappears if you cause a redraw (e.g., by resizing the window).

Examples Create a three-dimensional comet plot.

```
t = -10*pi:pi/250:10*pi;
comet3((cos(2*t).^2).*sin(t),(sin(2*t).^2).*cos(t),t);
```

See Also `comet`

"Direction and Velocity Plots" for related functions

Purpose Companion matrix

Syntax

```
A = compan(u)
```

Description `A = compan(u)` returns the corresponding companion matrix whose first row is `-u(2:n)/u(1)`, where `u` is a vector of polynomial coefficients. The eigenvalues of `compan(u)` are the roots of the polynomial.

Examples The polynomial $(x-1)(x-2)(x+3) = x^3 - 7x + 6$ has a companion matrix given by

```
u = [1  0  -7  6]
A = compan(u)
A =
    0    7   -6
    1    0    0
    0    1    0
```

The eigenvalues are the polynomial roots:

```
eig(compan(u))

ans =
    -3.0000
     2.0000
     1.0000
```

This is also `roots(u)`.

See Also `eig`, `poly`, `polyval`, `roots`

compass

Purpose

Plot arrows emanating from the origin

Syntax

```
compass(X,Y)
compass(Z)
compass(...,LineSpec)
h = compass(...)
```

Description

A compass plot displays direction or velocity vectors as arrows emanating from the origin. `X`, `Y`, and `Z` are in Cartesian coordinates and plotted on a circular grid.

`compass(X,Y)` displays a compass plot having *n* arrows, where *n* is the number of elements in `X` or `Y`. The location of the base of each arrow is the origin. The location of the tip of each arrow is a point relative to the base and determined by `[X(i),Y(i)]`.

`compass(Z)` displays a compass plot having *n* arrows, where *n* is the number of elements in `Z`. The location of the base of each arrow is the origin. The location of the tip of each arrow is relative to the base as determined by the real and imaginary components of `Z`. This syntax is equivalent to `compass(real(Z),imag(Z))`.

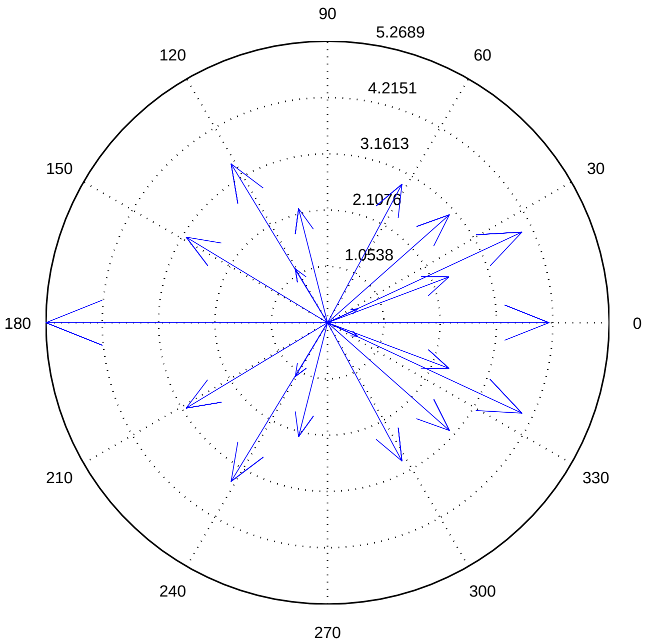
`compass(...,LineSpec)` draws a compass plot using the line type, marker symbol, and color specified by `LineSpec`.

`h = compass(...)` returns handles to line objects.

Examples

Draw a compass plot of the eigenvalues of a matrix.

```
Z = eig(randn(20,20));
compass(Z)
```



See Also

`feather`, `LineSpec`, `rose`

"Direction and Velocity Plots" for related functions

Compass Plots for another example

complex

Purpose

Construct complex data from real and imaginary components

Syntax

```
c = complex(a,b)
c = complex(a)
```

Description

`c = complex(a,b)` creates a complex output, `c`, from the two real inputs.

```
c = a + bi
```

The output is the same size as the inputs, which must be scalars or equally sized vectors, matrices, or multi-dimensional arrays of the same data type.

Note If `b` is all zeros, `c` is complex and the value of all its imaginary components is `0`. In contrast, the result of the addition `a+0i` returns a strictly real result.

`c = complex(a)` for real `a` returns the complex result `c` with real part `a` and `0` as the value of all imaginary components. Even though the value of all imaginary components is `0`, `c` is complex and `isreal(c)` returns false.

The `complex` function provides a useful substitute for expressions such as

```
a + i*b   or   a + j*b
```

in cases when the names "`i`" and "`j`" may be used for other variables (and do not equal $\sqrt{-1}$), when `a` and `b` are not double-precision, or when `b` is all zero.

Example

Create complex `uint8` vector from two real `uint8` vectors.

```
a = uint8([1;2;3;4])
b = uint8([2;2;7;7])

c = complex(a,b)

c =
   1.0000 + 2.0000i
   2.0000 + 2.0000i
   3.0000 + 7.0000i
   4.0000 + 7.0000i
```

See Also abs, angle, conj, i, imag, isreal, j, real

computer

Purpose

Identify information about computer on which MATLAB is running

Syntax

```
str = computer
[str,maxsize] = computer
[str,maxsize,endian] = computer
```

Description

`str = computer` returns the string `str` with the computer type on which MATLAB is running.

`[str,maxsize] = computer` returns the integer `maxsize`, which contains the maximum number of elements allowed in an array with this version of MATLAB.

`[str,maxsize,endian] = computer` also returns either `'L'` for little endian byte ordering or `'B'` for big endian byte ordering.

The list of supported computers changes as new computers are added and others become obsolete. A typical list follows.

str	Computer
ALPHA	Compaq Alpha (OSF1)
HP700	HP 9000/700 (HP-UX 10.20)
HPUX	HP PA-RISC (HP-UX 11.00)
IBM_RS	IBM RS6000 workstation (AIX)
GLNX86	Linux on PC
PCWIN	Microsoft Windows
SGI	Silicon Graphics (IRIX/IRIX64)
SOL2	Sun Solaris 2 SPARC workstation

Remarks

SGI64 users prior to R12 must migrate to SGI with R12.
LNX86 users prior to R12 must migrate to GLNX86 with R12.

See Also

`ispc`, `isunix`

Purpose

Condition number with respect to inversion

Syntax

```
c = cond(X)
c = cond(X,p)
```

Description

The *condition number* of a matrix measures the sensitivity of the solution of a system of linear equations to errors in the data. It gives an indication of the accuracy of the results from matrix inversion and the linear equation solution. Values of `cond(X)` and `cond(X,p)` near 1 indicate a well-conditioned matrix.

`c = cond(X)` returns the 2-norm condition number, the ratio of the largest singular value of `X` to the smallest.

`c = cond(X,p)` returns the matrix condition number in `p`-norm:

```
norm(X,p) * norm(inv(X),p
```

If `p` is...	Then `cond(X,p)` returns the...
`1`	1-norm condition number
`2`	2-norm condition number
`'fro'`	Frobenius norm condition number
`inf`	Infinity norm condition number

Algorithm

The algorithm for `cond` (when `p = 2`) uses the singular value decomposition, `svd`.

See Also

`condeig`, `condest`, `norm`, `normest`, `rank`, `rcond`, `svd`

References

[1] Anderson, E., Z. Bai, C. Bischof, S. Blackford, J. Demmel, J. Dongarra, J. Du Croz, A. Greenbaum, S. Hammarling, A. McKenney, and D. Sorensen, *LAPACK User's Guide* (`http://www.netlib.org/lapack/lug/lapack_lug.html`), Third Edition, SIAM, Philadelphia, 1999.

condeig

Purpose

Condition number with respect to eigenvalues

Syntax

```
c = condeig(A)
[V,D,s] = condeig(A)
```

Description

`c = condeig(A)` returns a vector of condition numbers for the eigenvalues of `A`. These condition numbers are the reciprocals of the cosines of the angles between the left and right eigenvectors.

`[V,D,s] = condeig(A)` is equivalent to

```
[V,D] = eig(A);
s = condeig(A);
```

Large condition numbers imply that `A` is near a matrix with multiple eigenvalues.

See Also

`balance`, `cond`, `eig`

Purpose

1-norm condition number estimate

Syntax

```
c = condest(A)
[c,v] = condest(A)
```

Description

`c = condest(A)` computes a lower bound C for the 1-norm condition number of a square matrix A.

`c = condest(A,t)` changes `t`, a positive integer parameter equal to the number of columns in an underlying iteration matrix. Increasing the number of columns usually gives a better condition estimate but increases the cost. The default is `t = 2`, which almost always gives an estimate correct to within a factor 2.

`[c,v] = condest(A)` also computes a vector `v` which is an approximate null vector if `c` is large. `v` satisfies `norm(A*v,1) = norm(A,1)*norm(v,1)/c`.

Note `condest` invokes `rand`. If repeatable results are required then invoke `rand('state',j)`, for some `j`, before calling this function.

This function is particularly useful for sparse matrices.

`condest` uses block 1-norm power method of Higham and Tisseur [1].

See Also

`cond`, `norm`, `normest`

Reference

[1] Higham, N. J. and F. Tisseur, "A Block Algorithm for Matrix 1-Norm Estimation, with an Application to 1-Norm Pseudospectra," *SIAM Journal Matrix Anal. Appl.*, Vol. 21, No. 4, 2000, pp.1185-1201.

Purpose Plot velocity vectors as cones in a 3-D vector field

Syntax

```
coneplot(X,Y,Z,U,V,W,Cx,Cy,Cz)
coneplot(U,V,W,Cx,Cy,Cz)
coneplot(...,s)
coneplot(...,color)
coneplot(...,'quiver')
coneplot(...,'method')
coneplot(X,Y,Z,U,V,W,'nointerp')
h = coneplot(...)
```

Description

`coneplot(X,Y,Z,U,V,W,Cx,Cy,Cz)` plots velocity vectors as cones pointing in the direction of the velocity vector and having a length proportional to the magnitude of the velocity vector.

- `X`, `Y`, `Z` define the coordinates for the vector field.
- `U`, `V`, `W` define the vector field. These arrays must be the same size, monotonic, and 3-D plaid (such as the data produced by `meshgrid`).
- `Cx`, `Cy`, `Cz` define the location of the cones in vector field. The section Starting Points for Stream Plots in Visualization Techniques provides more information on defining starting points.

`coneplot(U,V,W,Cx,Cy,Cz)` (omitting the `X`, `Y`, and `Z` arguments) assumes `[X,Y,Z] = meshgrid(1:n,1:m,1:p)` where `[m,n,p]= size(U)`.

`coneplot(...,s)` MATLAB automatically scales the cones to fit the graph and then stretches them by the scale factor `s`. If you do not specify a value for `s`, MATLAB uses a value of 1. Use `s = 0` to plot the cones without automatic scaling.

`coneplot(...,color)` interpolates the array `color` onto the vector field and then colors the cones according to the interpolated values. The size of the `color` array must be the same size as the `U`, `V`, `W` arrays. This option works only with cones (i.e., not with the `quiver` option).

`coneplot(...,'quiver')` draws arrows instead of cones (see `quiver3` for an illustration of a quiver plot).

`coneplot(...,'method')` specifies the interpolation method to use. *`method`* can be: `linear`, `cubic`, `nearest`. `linear` is the default (see `interp3` for a discussion of these interpolation methods)

`coneplot(X,Y,Z,U,V,W,'nointerp')` does not interpolate the positions of the cones into the volume. The cones are drawn at positions defined by `X`, `Y`, `Z` and are oriented according to `U`, `V`, `W`. Arrays `X`, `Y`, `Z`, `U`, `V`, `W` must all be the same size.

`h = coneplot(...)` returns the handle to the `patch` object used to draw the cones. You can use the `set` command to change the properties of the cones.

Remarks

`coneplot` automatically scales the cones to fit the graph, while keeping them in proportion to the respective velocity vectors.

It is usually best to set the data aspect ratio of the axes before calling `coneplot`. You can set the ratio using the `daspect` command,

```
daspect([1,1,1])
```

Examples

This example plots the velocity vector cones for vector volume data representing the motion of air through a rectangular region of space. The final graph employs a number of enhancements to visualize the data more effectively. These include:

- Cone plots indicate the magnitude and direction of the wind velocity.
- Slice planes placed at the limits of the data range provide a visual context for the cone plots within the volume.
- Directional lighting provides visual queues as to the orientation of the cones.
- View adjustments compose the scene to best reveal the information content of the data by selecting the view point, projection type, and magnification.

1. Load and Inspect Data

The winds data set contains six 3-D arrays: `u`, `v`, and `w` specify the vector components at each of the coordinate specified in `x`, `y`, and `z`. The coordinates define a lattice grid structure where the data is sampled within the volume.

It is useful to establish the range of the data to place the slice planes and to specify where you want the cone plots (min, max).

```
load wind
xmin = min(x(:));
xmax = max(x(:));
ymin = min(y(:));
ymax = max(y(:));
zmin = min(z(:));
```

2. Create the Cone Plot

- Decide where in data space you want to plot cones. This example selects the full range of x and y in eight steps and the range 3 to 15 in four steps in z (linspace, meshgrid).
- Use daspect to set the data aspect ratio of the axes before calling coneplot so MATLAB can determine the proper size of the cones.
- Draw the cones, setting the scale factor to 5 to make the cones larger than the default size.
- Set the coloring of each cone (FaceColor, EdgeColor).

```
daspect([2,2,1])
xrange = linspace(xmin,xmax,8);
yrange = linspace(ymin,ymax,8);
zrange = 3:4:15;
[cx cy cz] = meshgrid(xrange,yrange,zrange);
hcones = coneplot(x,y,z,u,v,w,cx,cy,cz,5);
set(hcones,'FaceColor','red','EdgeColor','none')
```

3. Add the Slice Planes

- Calculate the magnitude of the vector field (which represents wind speed) to generate scalar data for the `slice` command.
- Create slice planes along the x-axis at `xmin` and `xmax`, along the y-axis at `ymax`, and along the z-axis at `zmin`.
- Specify interpolated face color so the slice coloring indicates wind speed and do not draw edges (`hold`, `slice`, `FaceColor`, `EdgeColor`).

```
hold on
wind_speed = sqrt(u.^2 + v.^2 + w.^2);
hsurfaces = slice(x,y,z,wind_speed,[xmin,xmax],ymax,zmin);
set(hsurfaces,'FaceColor','interp','EdgeColor','none')
hold off
```

4. Define the View

- Use the `axis` command to set the axis limits equal to the range of the data.
- Orient the `view` to azimuth = 30 and elevation = 40 (`rotate3d` is a useful command for selecting the best view).
- Select perspective projection to provide a more realistic looking volume (`camproj`).
- Zoom in on the scene a little to make the plot as large as possible (`camzoom`).

```
axis tight; view(30,40); axis off
camproj perspective; camzoom(1.5)
```

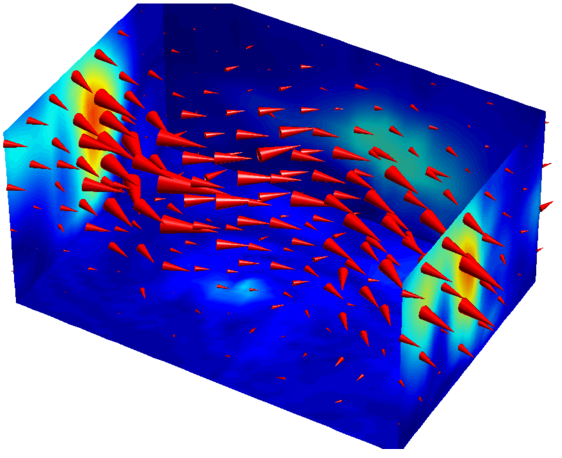
5. Add Lighting to the Scene

The light source affects both the slice planes (surfaces) and the cone plots (patches). However, you can set the lighting characteristics of each independently.

- Add a light source to the right of the camera and use Phong lighting give the cones and slice planes a smooth, three-dimensional appearance (`camlight`, `lighting`).
- Increase the value of the `AmbientStrength` property for each slice plane to improve the visibility of the dark blue colors. (Note that you can also specify a different `colormap` to change to coloring of the slice planes.)

- Increase the value of the DiffuseStrength property of the cones to brighten particularly those cones not showing specular reflections.

```
camlight right; lighting phong
set(hsurfaces,'AmbientStrength',.6)
set(hcones,'DiffuseStrength',.8)
```



See Also

isosurface, patch, reducevolume, smooth3, streamline, stream2, stream3, subvolume

[2] "Volume Visualization" for related functions

conj

Purpose Complex conjugate

Syntax

```
ZC = conj(Z)
```

Description `ZC = conj(Z)` returns the complex conjugate of the elements of `Z`.

Algorithm If `Z` is a complex array:

```
conj(Z) = real(Z) - i*imag(Z)
```

See Also `i`, `j`, `imag`, `real`

continue

Purpose Pass control to the next iteration of `for` or `while` loop

Syntax `continue`

Description `continue` passes control to the next iteration of the `for` or `while` loop in which it appears, skipping any remaining statements in the body of the loop.

In nested loops, `continue` passes control to the next iteration of the `for` or `while` loop enclosing it.

Examples The example below shows a `continue` loop that counts the lines of code in the file, `magic.m`, skipping all blank lines and comments. A `continue` statement is used to advance to the next line in `magic.m` without incrementing the count whenever a blank line or comment line is encountered.

```
fid = fopen('magic.m','r');
count = 0;
while ~feof(fid)
    line = fgetl(fid);
    if isempty(line) | strncmp(line,'%',1)
        continue
    end
    count = count + 1;
end
disp(sprintf('%d lines',count));
```

See Also `for`, `while`, `end`, `break`, `return`

Purpose Two-dimensional contour plot

Syntax

```
contour(Z)
contour(Z,n)
contour(Z,v)
contour(X,Y,Z)
contour(X,Y,Z,n)
contour(X,Y,Z,v)
contour(...,LineSpec)
[C,h] = contour(...)
```

Description A contour plot displays isolines of matrix `Z`. Label the contour lines using `clabel`.

`contour(Z)` draws a contour plot of matrix `Z`, where `Z` is interpreted as heights with respect to the *x*-*y* plane. `Z` must be at least a 2-by-2 matrix. The number of contour levels and the values of the contour levels are chosen automatically based on the minimum and maximum values of `Z`. The ranges of the *x*- and *y*-axis are `[1:n]` and `[1:m]`, where `[m,n] = size(Z)`.

`contour(Z,n)` draws a contour plot of matrix `Z` with `n` contour levels.

`contour(Z,v)` draws a contour plot of matrix `Z` with contour lines at the data values specified in vector `v`. The number of contour levels is equal to `length(v)`. To draw a single contour of level `i`, use `contour(Z,[i i])`.

`contour(X,Y,Z)`, `contour(X,Y,Z,n)`, and `contour(X,Y,Z,v)` draw contour plots of `Z`. `X` and `Y` specify the *x*- and *y*-axis limits. When `X` and `Y` are matrices, they must be the same size as `Z`, in which case they specify a surface as `surf` does.

`contour(...,LineSpec)` draws the contours using the line type and color specified by `LineSpec`. contour ignores marker symbols.

`[C,h] = contour(...)` returns the contour matrix `C` (see `contourc`) and a vector of handles to graphics objects. `clabel` uses the contour matrix `C` to create the labels. `contour` creates patch graphics objects unless you specify `LineSpec`, in which case `contour` creates line graphics objects.

Remarks

If you do not specify `LineSpec`, `colormap` and `caxis` control the color.

If `X` or `Y` is irregularly spaced, `contour` calculates contours using a regularly spaced contour grid, then transforms the data to `X` or `Y`.

Examples

To view a contour plot of the function

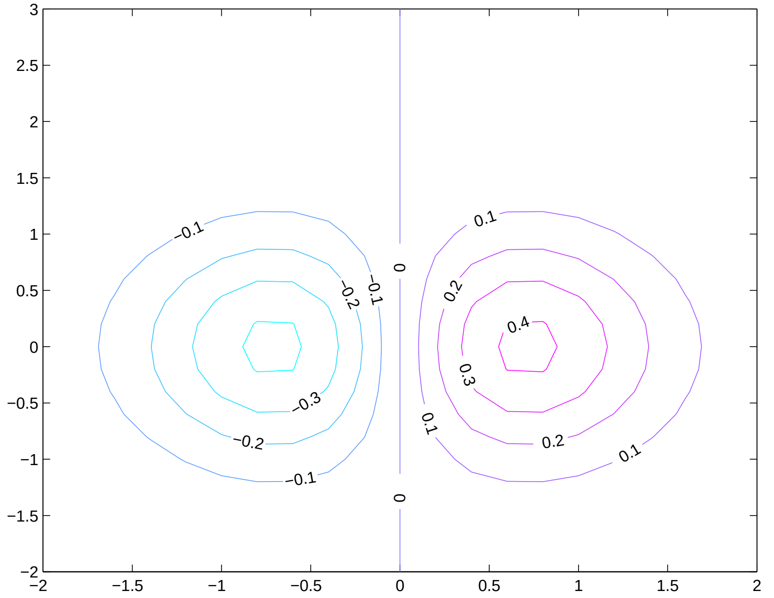
$$z = xe^{(-x^2 - y^2)}$$

over the range $-2 \le x \le 2$, $-2 \le y \le 3$, create matrix `Z` using the statements

```
[X,Y] = meshgrid(-2:.2:2,-2:.2:3);
Z = X.*exp(-X.^2-Y.^2);
```

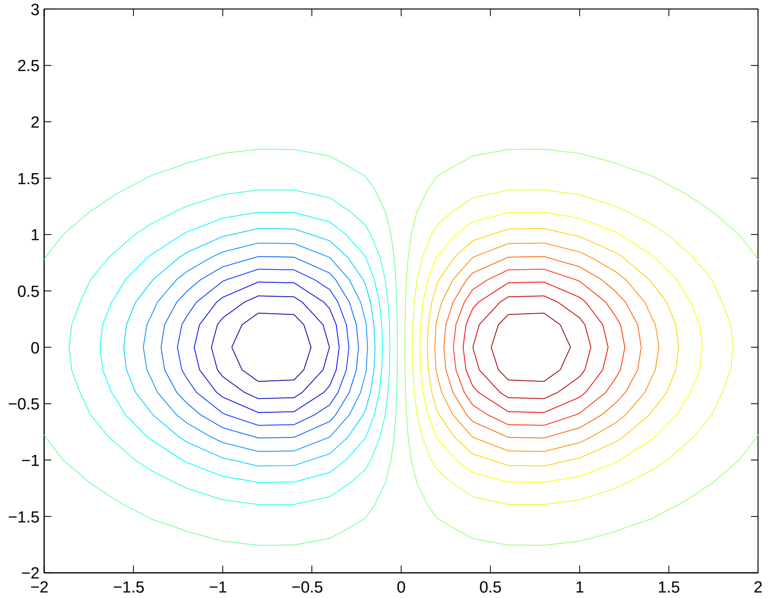
Then, generate a contour plot of `Z`.

```
[C,h] = contour(X,Y,Z);
clabel(C,h)
colormap cool
```



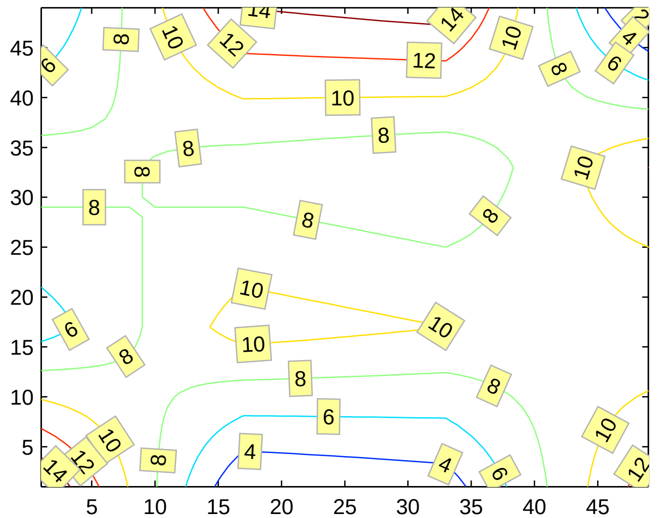
View the same function over the same range with 20 evenly spaced contour lines and colored with the default colormap `jet`.

```
contour(X,Y,Z,20)
```



Use `interp2` to create smoother contours. Also set the contour label text `BackgroundColor` to a light yellow and the `EdgeColor` to light gray.

```
Z = magic(4);
[C,h] = contour(interp2(Z,4));
h = clabel(C,h);
set(h,'BackgroundColor',[1 1 .6],...
    'Edgecolor',[.7 .7 .7])
```



See Also

`clabel`, `contour3`, `contourc`, `contourf`, `interp2`, `quiver`

"Contour Plots" category for related functions

Contour Plots section for more examples

Purpose

Three-dimensional contour plot

Syntax

```
contour3(Z)
contour3(Z,n)
contour3(Z,v)
contour3(X,Y,Z)
contour3(X,Y,Z,n)
contour3(X,Y,Z,v)
contour3(...,LineSpec)
[C,h] = contour3(...)
```

Description

`contour3` creates a three-dimensional contour plot of a surface defined on a rectangular grid.

`contour3(Z)` draws a contour plot of matrix `Z` in a three-dimensional view. `Z` is interpreted as heights with respect to the *x*-*y* plane. `Z` must be at least a 2-by-2 matrix. The number of contour levels and the values of contour levels are chosen automatically. The ranges of the *x*- and *y*-axis are `[1:n]` and `[1:m]`, where `[m,n] = size(Z)`.

`contour3(Z,n)` draws a contour plot of matrix `Z` with `n` contour levels in a three-dimensional view.

`contour3(Z,v)` draws a contour plot of matrix `Z` with contour lines at the values specified in vector `v`. The number of contour levels is equal to `length(v)`. To draw a single contour of level `i`, use `contour(Z,[i i])`.

`contour3(X,Y,Z)`, `contour3(X,Y,Z,n)`, and `contour3(X,Y,Z,v)` use `X` and `Y` to define the *x*- and *y*-axis limits. If `X` is a matrix, `X(1,:)` defines the *x*-axis. If `Y` is a matrix, `Y(:,1)` defines the *y*-axis. When `X` and `Y` are matrices, they must be the same size as `Z`, in which case they specify a surface as `surf` does.

`contour3(...,LineSpec)` draws the contours using the line type and color specified by `LineSpec`.

`[C,h] = contour3(...)` returns the contour matrix `C` as described in the function `contourc` and a column vector containing handles to graphics objects. `contour3` creates patch graphics objects unless you specify `LineSpec`, in which case `contour3` creates line graphics objects.

Remarks

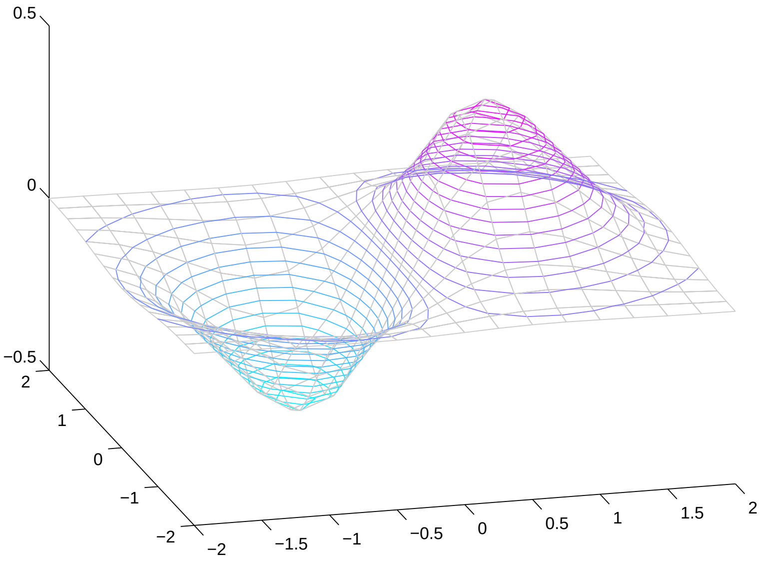
If you do not specify `LineSpec`, `colormap` and `caxis` control the color.

If `X` or `Y` is irregularly spaced, `contour3` calculates contours using a regularly spaced contour grid, then transforms the data to `X` or `Y`.

Examples

Plot the three-dimensional contour of a function and superimpose a surface plot to enhance visualization of the function.

```
[X,Y] = meshgrid([-2:.25:2]);
Z = X.*exp(-X.^2-Y.^2);
contour3(X,Y,Z,30)
surface(X,Y,Z,'EdgeColor',[.8 .8 .8],'FaceColor','none')
grid off
view(-15,25)
colormap cool
```



See Also

`contour`, `contourc`, `meshc`, `meshgrid`, `surfc`

"Contour Plots" category for related functions

Contour Plots section for more examples

Purpose

Low-level contour plot computation

Syntax

```
C = contourc(Z)
C = contourc(Z,n)
C = contourc(Z,v)
C = contourc(x,y,Z)
C = contourc(x,y,Z,n)
C = contourc(x,y,Z,v)
```

Description

`contourc` calculates the contour matrix `C` used by `contour`, `contour3`, and `contourf`. The values in `Z` determine the heights of the contour lines with respect to a plane. The contour calculations use a regularly spaced grid determined by the dimensions of `Z`.

`C = contourc(Z)` computes the contour matrix from data in matrix `Z`, where `Z` must be at least a 2-by-2 matrix. The contours are isolines in the units of `Z`. The number of contour lines and the corresponding values of the contour lines are chosen automatically.

`C = contourc(Z,n)` computes contours of matrix `Z` with `n` contour levels.

`C = contourc(Z,v)` computes contours of matrix `Z` with contour lines at the values specified in vector `v`. The length of `v` determines the number of contour levels. To compute a single contour of level `i`, use `contourc(Z,[i i])`.

`C = contourc(x,y,Z)`, `C = contourc(x,y,Z,n)`, and `C = contourc(x,y,Z,v)` compute contours of `Z` using vectors `x` and `y` to determine the *x*- and *y*-axis limits. `x` and `y` must be monotonically increasing.

Remarks

`C` is a two-row matrix specifying all the contour lines. Each contour line defined in matrix `C` begins with a column that contains the value of the contour (specified by `v` and used by `clabel`), and the number of `(x,y)` vertices in the contour line. The remaining columns contain the data for the `(x,y)`pairs.

```
C = [value1 xdata(1) xdata(2)...value2 xdata(1) xdata(2)...;
     dim1   ydata(1) ydata(2)...dim2   ydata(1) ydata(2)...]
```

Specifying irregularly spaced `x` and `y` vectors is not the same as contouring irregularly spaced data. If `x` or `y` is irregularly spaced, `contourc` calculates contours using a regularly spaced contour grid, then transforms the data to `x` or `y`.

See Also

`clabel`, `contour`, `contour3`, `contourf`

"Contour Plots" for related functions

The Contouring Algorithm for more information

Purpose

Filled two-dimensional contour plot

Syntax

```
contourf(Z)
contourf(Z,n)
contourf(Z,v)
contourf(X,Y,Z)
contourf(X,Y,Z,n)
contourf(X,Y,Z,v)
[C,h,CF] = contourf(...)
```

Description

A filled contour plot displays isolines calculated from matrix `Z` and fills the areas between the isolines using constant colors. The color of the filled areas depends on the current figure's colormap.

`contourf(Z)` draws a contour plot of matrix `Z`, where `Z` is interpreted as heights with respect to a plane. `Z` must be at least a 2-by-2 matrix. The number of contour lines and the values of the contour lines are chosen automatically.

`contourf(Z,n)` draws a contour plot of matrix `Z` with `n` contour levels.

`contourf(Z,v)` draws a contour plot of matrix `Z` with contour levels at the values specified in vector `v`.

`contourf(X,Y,Z)`, `contourf(X,Y,Z,n)`, and `contourf(X,Y,Z,v)` produce contour plots of `Z` using `X` and `Y` to determine the *x*- and *y*-axis limits. When `X` and `Y` are matrices, they must be the same size as `Z`, in which case they specify a surface as `surf` does.

`[C,h,CF] = contourf(...)` returns the contour matrix `C` as calculated by the function `contourc` and used by `clabel`, a vector of handles `h` to patch graphics objects, and a contour matrix `CF` for the filled areas.

Remarks

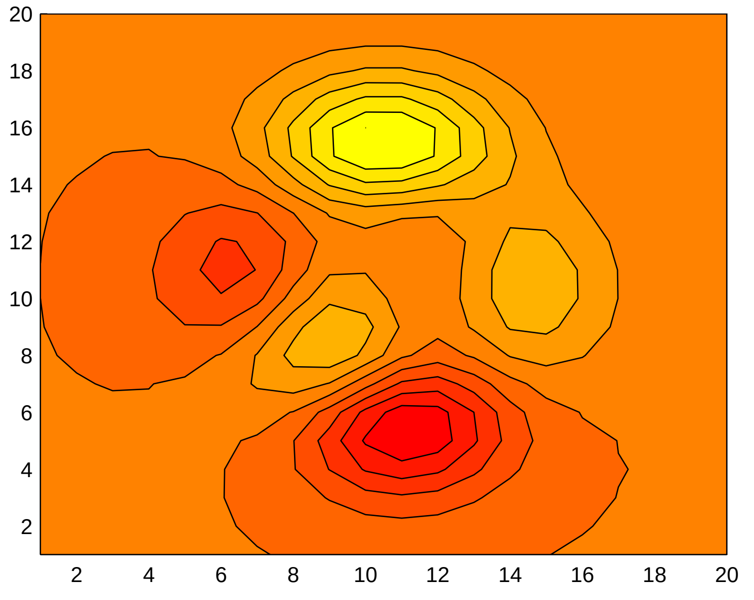
If `X` or `Y` is irregularly spaced, `contourf` calculates contours using a regularly spaced contour grid, then transforms the data to `X` or `Y`.

Examples

Create a filled contour plot of the `peaks` function.

```
[C,h] = contourf(peaks(20),10);
```

```
colormap autumn
```



See Also `clabel`, `contour`, `contour3`, `contourc`, `quiver`

"Contour Plots" for related functions

Purpose

Draw contours in volume slice planes

Syntax

```
contourslice(X,Y,Z,V,Sx,Sy,Sz)
contourslice(X,Y,Z,V,Xi,Yi,Zi)
contourslice(V,Sx,Sy,Sz), contourslice(V,Xi,Yi,Zi)
contourslice(...,n)
contourslice(...,cvals)
contourslice(...,[cv cv])
contourslice(...,'method')
h = contourslice(...)
```

Description

`contourslice(X,Y,Z,V,Sx,Sy,Sz)` draws contours in the x-, y-, and z-axis aligned planes at the points in the vectors `Sx`, `Sy`, `Sz`. The arrays `X`, `Y`, and `Z` define the coordinates for the volume `V` and must be monotonic and 3-D plaid (such as the data produced by `meshgrid`) The color at each contour is determined by the volume `V`, which must be an m-by-n-by-p volume array.

`contourslice(X,Y,Z,V,Xi,Yi,Zi)` draws contours through the volume `V` along the surface defined by the arrays `Xi,Yi,Zi`.

`contourslice(V,Sx,Sy,Sz)` and `contourslice(V,Xi,Yi,Zi)` (omitting the `X`, `Y`, and `Z` arguments) assumes `[X,Y,Z] = meshgrid(1:n,1:m,1:p)` where `[m,n,p]= size(v)`.

`contourslice(...,n)` draws `n` contour lines per plane, overriding the automatic value.

`contourslice(...,cvals)` draws `length(cval)` contour lines per plane at the values specified in vector `cvals`.

`contourslice(...,[cv cv])` computes a single contour per plane at the level `cv`.

`contourslice(...,'`*`method`*`')` specifies the interpolation method to use. *`method`* can be: `linear`, `cubic`, `nearest`. `nearest` is the default except when the contours are being drawn along the surface defined by `Xi`, `Yi`, `Zi`, in which case `linear` is the default (see `interp3` for a discussion of these interpolation methods).

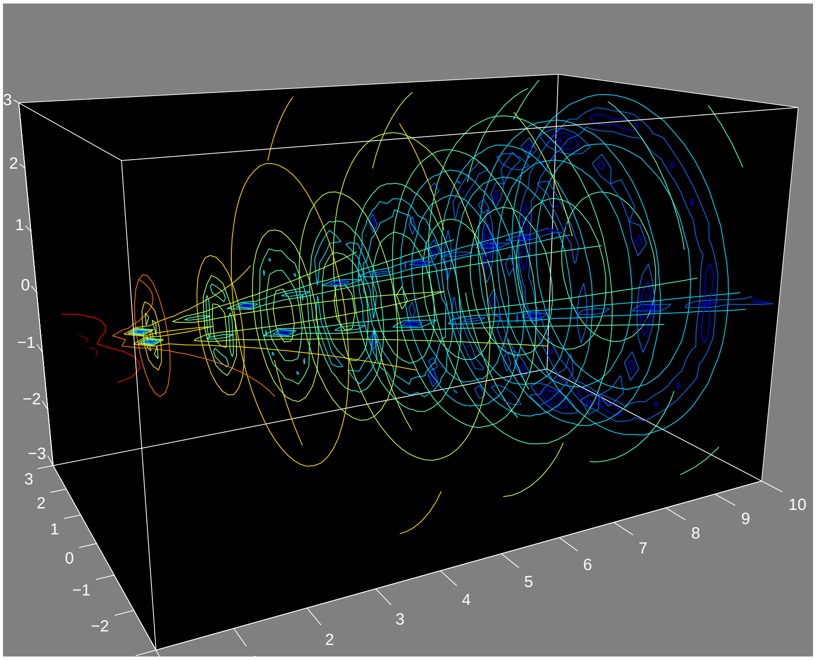
`h = contourslice(...)` returns a vector of handles to `patch` objects that are used to implement the contour lines.

Examples

This example uses the `flow` data set to illustrate the use of contoured slice planes (type `doc flow` for more information on this data set). Notice that this example:

- Specifies a vector of `length = 9` for `Sx`, an empty vector for the `Sy`, and a scalar value (0) for `Sz`. This creates nine contour plots along the x direction in the y-z plane, and one in the x-y plane at z = 0.
- Uses `linspace` to define a ten-element linearly spaced vector of values from -8 to 2 that specifies the number of contour lines to draw at each interval.
- Defines the view and projection type (`camva`, `camproj`, `campos`)
- Sets figure (`gcf`) and axes (`gca`) characteristics.

```
[x y z v] = flow;
h = contourslice(x,y,z,v,[1:9],[],[0],linspace(-8,2,10));
axis([0,10,-3,3,-3,3]); daspect([1,1,1])
camva(24); camproj perspective;
campos([-3,-15,5])
set(gcf,'Color',[.5,.5,.5],'Renderer','zbuffer')
set(gca,'Color','black','XColor','white', ...
   'YColor','white','ZColor','white')
box on
```



See Also

`isosurface`, `smooth3`, `subvolume`, `reducevolume`

“Volume Visualization” for related functions

contrast

Purpose

Grayscale colormap for contrast enhancement

Syntax

```
cmap = contrast(X)
cmap = contrast(X,m)
```

Description

The `contrast` function enhances the contrast of an image. It creates a new gray colormap, `cmap`, that has an approximately equal intensity distribution. All three elements in each row are identical.

`cmap = contrast(X)` returns a gray colormap that is the same length as the current colormap.

`cmap = contrast(X,m)` returns an `m`-by-3 gray colormap.

Examples

Add contrast to the clown image defined by `X`.

```
load clown;
cmap = contrast(X);
image(X);
colormap(cmap);
```

See Also

`brighten`, `colormap`, `image`

“Colormaps” for related functions

Purpose

Convolution and polynomial multiplication

Syntax

```
w = conv(u,v)
```

Description

`w = conv(u,v)` convolves vectors `u` and `v`. Algebraically, convolution is the same operation as multiplying the polynomials whose coefficients are the elements of `u` and `v`.

Definition

Let `m = length(u)` and `n = length(v)`. Then `w` is the vector of length `m+n-1` whose `k`th element is

$$w(k) = \sum_j u(j)v(k+1-j)$$

The sum is over all the values of `j` which lead to legal subscripts for `u(j)` and `v(k+1-j)`, specifically `j = max(1,k+1-n):min(k,m)`. When `m = n`, this gives

```
w(1) = u(1)*v(1)
w(2) = u(1)*v(2)+u(2)*v(1)
w(3) = u(1)*v(3)+u(2)*v(2)+u(3)*v(1)
...
w(n) = u(1)*v(n)+u(2)*v(n-1)+ ... +u(n)*v(1)
...
w(2*n-1) = u(n)*v(n)
```

Algorithm

The convolution theorem says, roughly, that convolving two sequences is the same as multiplying their Fourier transforms. In order to make this precise, it is necessary to pad the two vectors with zeros and ignore roundoff error. Thus, if

```
X = fft([x zeros(1,length(y)-1)])
```

and

```
Y = fft([y zeros(1,length(x)-1)])
```

then `conv(x,y) = ifft(X.*Y)`

See Also

`conv2`, `convn`, `deconv`, `filter`

`convmtx` and `xcorr` in the Signal Processing Toolbox

conv2

Purpose Two-dimensional convolution

Syntax

```
C = conv2(A,B)
C = conv2(hcol,hrow,A)
C = conv2(...,'shape')
```

Description `C = conv2(A,B)` computes the two-dimensional convolution of matrices `A` and `B`. If one of these matrices describes a two-dimensional finite impulse response (FIR) filter, the other matrix is filtered in two dimensions.

The size of `C` in each dimension is equal to the sum of the corresponding dimensions of the input matrices, minus one. That is, if the size of `A` is `[ma,na]` and the size of `B` is `[mb,nb]`, then the size of `C` is `[ma+mb-1,na+nb-1]`.

`C = conv2(hcol,hrow,A)` convolves `A` first with the vector `hcol` along the rows and then with the vector `hrow` along the columns. If `hcol` is a column vector and `hrow` is a row vector, this case is the same as `C = conv2(hcol*hrow,A)`.

`C = conv2(...,'shape')` returns a subsection of the two-dimensional convolution, as specified by the `shape` parameter:

`full`	Returns the full two-dimensional convolution (default).
`same`	Returns the central part of the convolution of the same size as `A`.
`valid`	Returns only those parts of the convolution that are computed without the zero-padded edges. Using this option, `C` has size `[ma-mb+1,na-nb+1]` when `all(size(A) >= size(B))`. Otherwise `conv2` returns `[]`.

Algorithm `conv2` uses a straightforward formal implementation of the two-dimensional convolution equation in spatial form. If a and b are functions of two discrete variables, n_1 and n_2, then the formula for the two-dimensional convolution of a and b is

$$c(n_1, n_2) = \sum_{k_1 = -\infty}^{\infty} \sum_{k_2 = -\infty}^{\infty} a(k_1, k_2)\, b(n_1 - k_1, n_2 - k_2)$$

In practice however, `conv2` computes the convolution for finite intervals.

Note that matrix indices in MATLAB always start at 1 rather than 0. Therefore, matrix elements `A(1,1)`, `B(1,1)`, and `C(1,1)` correspond to mathematical quantities $a(0,0)$, $b(0,0)$, and $c(0,0)$.

Examples

Example 1. For the `'same'` case, conv2 returns the central part of the convolution. If there are an odd number of rows or columns, the "center" leaves one more at the beginning than the end.

This example first computes the convolution of A using the default (`'full'`) shape, then computes the convolution using the `'same'` shape. Note that the array returned using `'same'` corresponds to the underlined elements of the array returned using the default shape.

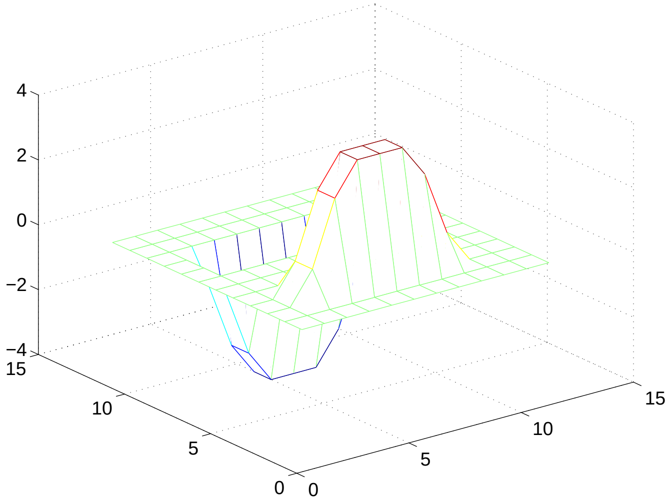
```
A = rand(3);
B = rand(4);
C = conv2(A,B)          % C is 6-by-6

C =
   0.1838  0.2374  0.9727  1.2644  0.7890  0.3750
   0.6929  1.2019  1.5499  2.1733  1.3325  0.3096
   0.5627  1.5150  2.3576  3.1553  2.5373  1.0602
   0.9986  2.3811  3.4302  3.5128  2.4489  0.8462
   0.3089  1.1419  1.8229  2.1561  1.6364  0.6841
   0.3287  0.9347  1.6464  1.7928  1.2422  0.5423

Cs = conv2(A,B,'same')   % Cs is the same size as A: 3-by-3
Cs =
   2.3576  3.1553  2.5373
   3.4302  3.5128  2.4489
   1.8229  2.1561  1.6364
```

Example 2. In image processing, the Sobel edge finding operation is a two-dimensional convolution of an input array with the special matrix

```
s = [1 2 1; 0 0 0; -1 -2 -1];
```

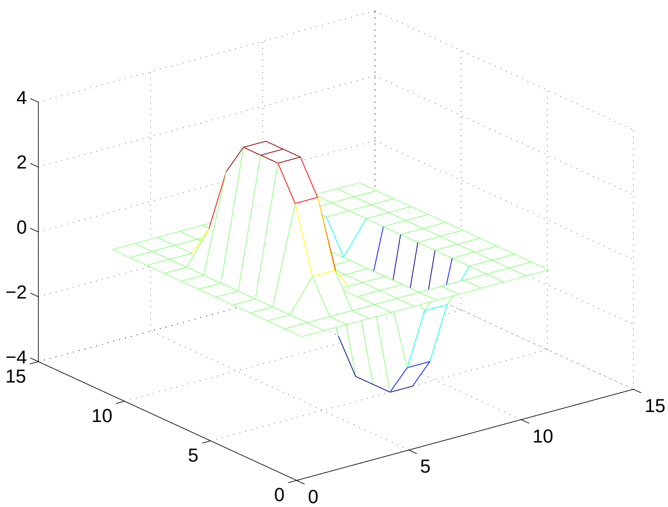
These commands extract the horizontal edges from a raised pedestal.

```
A = zeros(10);
A(3:7,3:7) = ones(5);
H = conv2(A,s);
mesh(H)
```



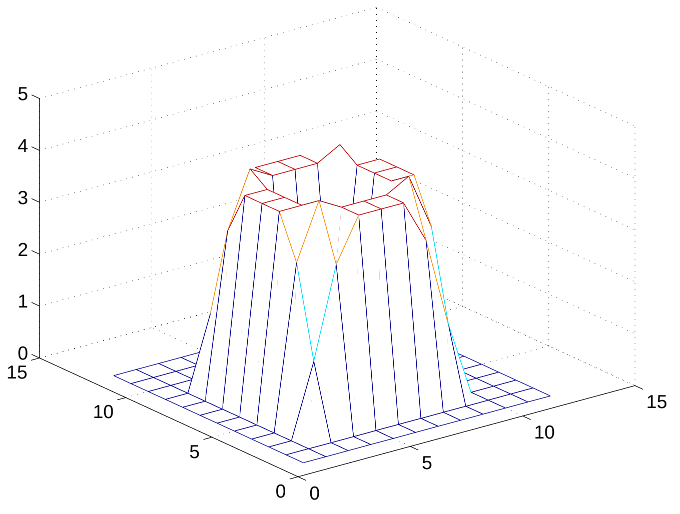
Transposing the filter s extracts the vertical edges of A.

```
V = conv2(A,s');
figure, mesh(V)
```



This figure combines both horizontal and vertical edges.

```
figure
mesh(sqrt(H.^2 + V.^2))
```



See Also

conv, convn, filter2

xcorr2 in the Signal Processing Toolbox

convhull

Purpose Convex hull

Syntax

```
K = convhull(x,y)
[K,a] = convhull(x,y)
```

Description

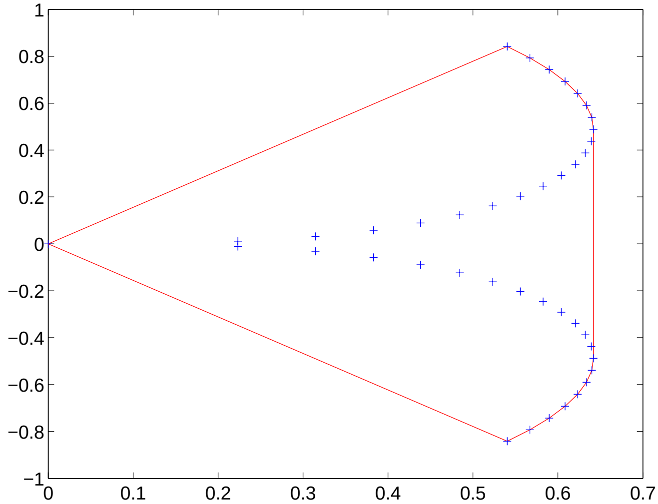
`K = convhull(x,y)` returns indices into the `x` and `y` vectors of the points on the convex hull.

`[K,a] = convhull(x,y)` also returns the area of the convex hull.

Visualization Use `plot` to plot the output of `convhull`.

Examples

```
xx = -1:.05:1; yy = abs(sqrt(xx));
[x,y] = pol2cart(xx,yy);
k = convhull(x,y);
plot(x(k),y(k),'r-',x,y,'b+')
```



Algorithm

`convhull` is based on Qhull [2]. It uses the Qhull joggle option (`'QJ'`). For information about `qhull`, see `http://www.geom.umn.edu/software/qhull/`. For copyright information, see `http://www.geom.umn.edu/software/download/COPYING.html`.

See Also `convhulln`, `delaunay`, `plot`, `polyarea`, `voronoi`

Reference

[1] Barber, C. B., D.P. Dobkin, and H.T. Huhdanpaa, "The Quickhull Algorithm for Convex Hulls," *ACM Transactions on Mathematical Software*, Vol. 22, No. 4, Dec. 1996, p. 469-483. Available in HTML format at `http://www.acm.org/pubs/citations/journals/toms/1996-22-4/p469-barber/` and in PostScript format at `ftp://geom.umn.edu/pub/software/qhull-96.ps`.

[2] National Science and Technology Research Center for Computation and Visualization of Geometric Structures (The Geometry Center), University of Minnesota. 1993.

convhulln

Purpose n-D convex hull

Syntax

```
K = convhulln(X)
[K,v] = convhulln(X)
```

Description `K = convhulln(X)` returns the indices `K` of the points in `X` that comprise the facets of the convex hull of `X`. `X` is an `m`-by-`n` array representing `m` points in `n`-D space. If the convex hull has `p` facets then `K` is `p`-by-`n`.

`[K,v] = convhulln(X)` also returns the volume `v` of the convex hull.

Visualization Plotting the output of `convhulln` depends on the value of `n`:

- For `n = 2`, use `plot` as you would for `convhull`.
- For `n = 3`, you can use `trisurf` to plot the output. The calling sequence is

  ```
  K = convhulln(X);
  trisurf(K,(X(:,1),X(:,2),X(:,3))
  ```

  For more control over the color of the facets, use `patch` to plot the output. For an example, see “Tessellation and Interpolation of Scattered Data in Higher Dimensions” in the MATLAB documentation.
- You cannot plot `convhulln` output for `n > 3`.

Algorithm `convhulln` is based on Qhull [2]. It uses the Qhull joggle option (`'QJ'`). For information about `qhull`, see `http://www.geom.umn.edu/software/qhull/`. For copyright information, see `http://www.geom.umn.edu/software/download/COPYING.html`.

See Also `convhull`, `delaunayn`, `dsearchn`, `tsearchn`, `voronoin`

Reference

[1] Barber, C. B., D.P. Dobkin, and H.T. Huhdanpaa, "The Quickhull Algorithm for Convex Hulls," *ACM Transactions on Mathematical Software*, Vol. 22, No. 4, Dec. 1996, p. 469-483. Available in HTML format at `http://www.acm.org/pubs/citations/journals/toms/1996-22-4/p469-barber/` and in PostScript format at `ftp://geom.umn.edu/pub/software/qhull-96.ps`.

[2] National Science and Technology Research Center for Computation and Visualization of Geometric Structures (The Geometry Center), University of Minnesota. 1993.

Purpose N-dimensional convolution

Syntax

```
C = convn(A,B)
C = convn(A,B,'shape')
```

Description

`C = convn(A,B)` computes the N-dimensional convolution of the arrays `A` and `B`. The size of the result is `size(A)+size(B)-1`.

`C = convn(A,B,'shape')` returns a subsection of the N-dimensional convolution, as specified by the `shape` parameter:

`'full'`	Returns the full N-dimensional convolution (default).
`'same'`	Returns the central part of the result that is the same size as `A`.
`'valid'`	Returns only those parts of the convolution that can be computed without assuming that the array `A` is zero-padded. The size of the result is `max(size(A)-size(B) + 1, 0)`

See Also

`conv`, `conv2`

Purpose Copy file or directory

Graphical Interface As an alternative to the `copyfile` function, use the Current Directory browser. Select the files and then select copy and paste commands from the **Edit** menu.

Syntax

```
copyfile('source','destination')
copyfile('source','destination','f')
[status,message,messageid] = copyfile('source','destination','f')
```

Description

`copyfile('source','destination')` copies the file or directory, `source` (and all its contents) to the file or directory, `destination`, where `source` and `destination` are the absolute or relative pathnames for the directory or file. If `source` is a directory, `destination` cannot be a file. If `source` is a directory, `copyfile` copies the contents of `source`, not the directory itself. To rename a file or directory when copying it, make `destination` a different name than `source`. If `destination` already exists, `copyfile` replaces it without warning. Use the wildcard **`*`** at the end of `source` to copy all matching files. Note that the read-only and archive attributes of `source` are not preserved in `destination`.

`copyfile('source','destination','f')` copies `source` to `destination`, regardless of the read-only attribute of `destination`.

`[status,message,messageid] = copyfile('source','destination','f')` copies `source` to `destination`, returning the status, a message, and the MATLAB error message ID (see `error` and `lasterr`). Here, `status` is `1` for success and is `0` for no error. Only one output argument is required and the **`f`** input argument is optional.

Examples

Copy File in Current Directory, Assigning a New Name to It

To make a copy of a file `myfun.m` in the current directory, assigning it the name `myfun2.m`, type

```
copyfile('myfun.m','myfun2.m')
```

Copy File to Another Directory

To copy `myfun.m` to the directory `d:/work/myfiles`, keeping the same filename, type

```
copyfile('myfun.m','d:/work/myfiles')
```

Copy All Matching Files by Using a Wildcard

To copy all files in the directory `myfiles` whose names begin with `my` to the directory `newprojects`, where `newprojects` is at the same level as the current directory, type

```
copyfile('myfiles/my*','../newprojects')
```

Copy Directory and Return Status

In this example, all files and subdirectories in the current directory's `myfiles` directory are copied to the `directory d:/work/myfiles`. Note that before running the `copyfile` function, `d:/work` does not contain the directory `myfiles`. It is created because `myfiles` is appended to `destination` in the `copyfile` function:

```
[s,mess,messid]=copyfile('myfiles','d:/work/myfiles')
s =
     1

mess =
     ''

messid =
     ''
```

The message returned indicates that `copyfile` was successful.

Copy File to Read-Only Directory

Copy `myfile.m` from the current directory to `d:/work/restricted`, where `restricted` is a read-only directory:

```
copyfile('myfile.m','d:/work/restricted','f')
```

After the copy, `myfile.m` exists in `d:/work/restricted`.

See Also

`delete`, `dir`, `fileattrib`, `filebrowser`, `mkdir`, `movefile`, `rmdir`

Purpose Copy graphics objects and their descendants

Syntax

```
new_handle = copyobj(h,p)
```

Description

`copyobj` creates copies of graphics objects. The copies are identical to the original objects except the copies have different values for their `Parent` property and a new handle. The new parent must be appropriate for the copied object (e.g., you can copy a line object only to another axes object).

`new_handle = copyobj(h,p)` copies one or more graphics objects identified by `h` and returns the handle of the new object or a vector of handles to new objects. The new graphics objects are children of the graphics objects specified by `p`.

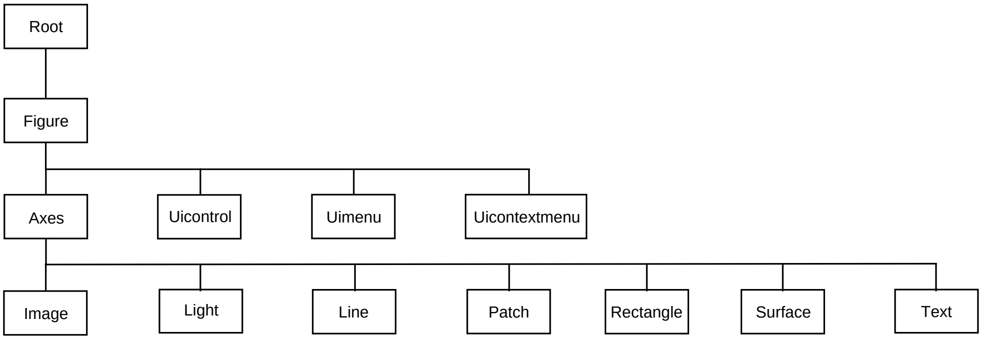
Remarks

`h` and `p` can be scalars or vectors. When both are vectors, they must be the same length and the output argument, `new_handle`, is a vector of the same length. In this case, `new_handle(i)` is a copy of `h(i)` with its `Parent` property set to `p(i)`.

When `h` is a scalar and `p` is a vector, `h` is copied once to each of the parents in `p`. Each `new_handle(i)` is a copy of `h` with its `Parent` property set to `p(i)`, and `length(new_handle)` equals `length(p)`.

When `h` is a vector and `p` is a scalar, each `new_handle(i)` is a copy of `h(i)` with its `Parent` property set to `p`. The length of `new_handle` equals `length(h)`.

Graphics objects are arranged as a hierarchy. Here, each graphics object is shown connected below its appropriate parent object.



Examples

Copy a surface to a new axes within a different figure.

```
h = surf(peaks);
colormap hot
figure      % Create a new figure
axes        % Create an axes object in the figure
new_handle = copyobj(h,gca);
colormap hot
view(3)
grid on
```

Note that while the surface is copied, the colormap (figure property), view, and grid (axes properties) are not copies.

See Also

`findobj`, `gcf`, `gca`, `gco`, `get`, `set`

`Parent` property for all graphics objects

"Finding and Identifying Graphics Objects" for related functions

Purpose Correlation coefficients

Syntax

```
R = corrcoef(X)
R = corrcoef(x,y)
[R,P]=corrcoef(...)
[R,P,RLO,RUP]=corrcoef(...)
[...]=corrcoef(...,'param1',val1,'param2',val2,...)
```

Description

`R = corrcoef(X)` returns a matrix `R` of correlation coefficients calculated from an input matrix `X` whose rows are observations and whose columns are variables. The matrix `R = corrcoef(X)` is related to the covariance matrix `C = cov(X)` by

$$R(i,j) = \frac{C(i,j)}{\sqrt{C(i,i)C(j,j)}}$$

`corrcoef(X)` is the zeroth lag of the covariance function, that is, the zeroth lag of `xcov(x,'coeff')` packed into a square array.

`R = corrcoef(x,y)` where `x` and `y` are column vectors is the same as `corrcoef([x y])`.

`[R,P]=corrcoef(...)` also returns `P`, a matrix of p-values for testing the hypothesis of no correlation. Each p-value is the probability of getting a correlation as large as the observed value by random chance, when the true correlation is zero. If `P(i,j)` is small, say less than `0.05`, then the correlation `R(i,j)` is significant.

`[R,P,RLO,RUP]=corrcoef(...)` also returns matrices `RLO` and `RUP`, of the same size as `R`, containing lower and upper bounds for a 95% confidence interval for each coefficient.

`[...]=corrcoef(...,'param1',val1,'param2',val2,...)` specifies additional parameters and their values. Valid parameters are the following.

'alpha'	A number between 0 and 1 to specify a confidence level of 100*(1 - alpha)%. Default is 0.05 for 95% confidence intervals.
'rows'	Either 'all' (default) to use all rows, 'complete' to use rows with no NaN values, or 'pairwise' to compute R(i,j) using rows with no NaN values in either column i or j.

The p-value is computed by transforming the correlation to create a t statistic having n-2 degrees of freedom, where n is the number of rows of X. The confidence bounds are based on an asymptotic normal distribution of 0.5*log((1+R)/(1-R)), with an approximate variance equal to 1/(n-3). These bounds are accurate for large samples when X has a multivariate normal distribution. The 'pairwise' option can produce an R matrix that is not positive definite.

Examples

Generate random data having correlation between column 4 and the other columns.

```
x = randn(30,4);     % Uncorrelated data
x(:,4) = sum(x,2);   % Introduce correlation.
[r,p] = corrcoef(x)  % Compute sample correlation and p-values.
[i,j] = find(p<0.05);  % Find significant correlations.
[i,j]                % Display their (row,col) indices.

r =
    1.0000   -0.3566    0.1929    0.3457
   -0.3566    1.0000   -0.1429    0.4461
    0.1929   -0.1429    1.0000    0.5183
    0.3457    0.4461    0.5183    1.0000

p =
    1.0000    0.0531    0.3072    0.0613
    0.0531    1.0000    0.4511    0.0135
    0.3072    0.4511    1.0000    0.0033
    0.0613    0.0135    0.0033    1.0000

ans =
     4     2
     4     3
     2     4
```

3 4

See Also

cov, mean, std

xcorr, xcov in the Signal Processing Toolbox

Purpose Cosine

Syntax

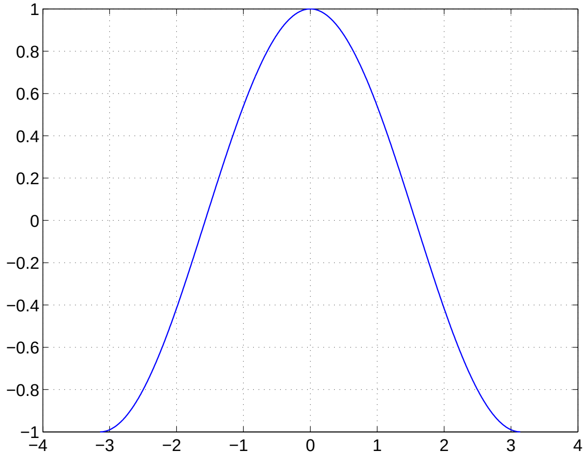
```
Y = cos(X)
```

Description The `cos` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

`Y = cos(X)` returns the circular cosine for each element of `X`.

Examples Graph the cosine function over the domain $-\pi \leq x \leq \pi$.

```
x = -pi:0.01:pi;
plot(x,cos(x)), grid on
```



The expression `cos(pi/2)` is not exactly zero but a value the size of the floating-point accuracy, `eps`, because `pi` is only a floating-point approximation to the exact value of π.

Definition The cosine can be defined as

$$\cos(x+iy) = \cos(x)\cosh(y) - i\sin(x)\sinh(y)$$

$$\cos(z) = \frac{e^{iz} + e^{-iz}}{2}$$

Algorithm

cos uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also

acos, acosh, cosh

cosh

Purpose

Hyperbolic cosine

Syntax

```
Y = cosh(X)
```

Description

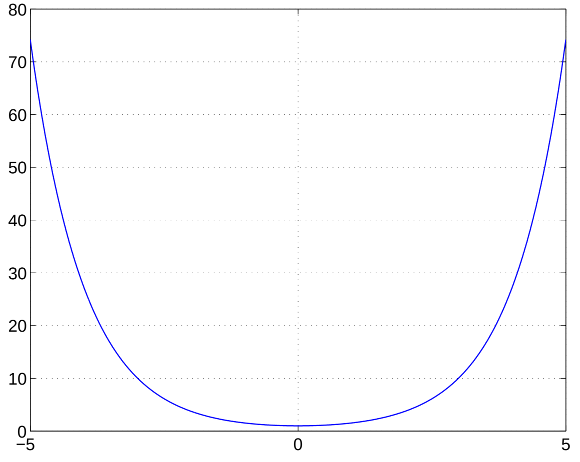
The cosh function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

`Y = cosh(X)` returns the hyperbolic cosine for each element of `X`.

Examples

Graph the hyperbolic cosine function over the domain $-5 \leq x \leq 5$.

```
x = -5:0.01:5;
plot(x,cosh(x)), grid on
```



Definition

The hyperbolic cosine can be defined as

$$\cosh(z) = \frac{e^{z} + e^{-z}}{2}$$

Algorithm

cosh uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also acos, acosh, cos

Purpose Cotangent

Syntax

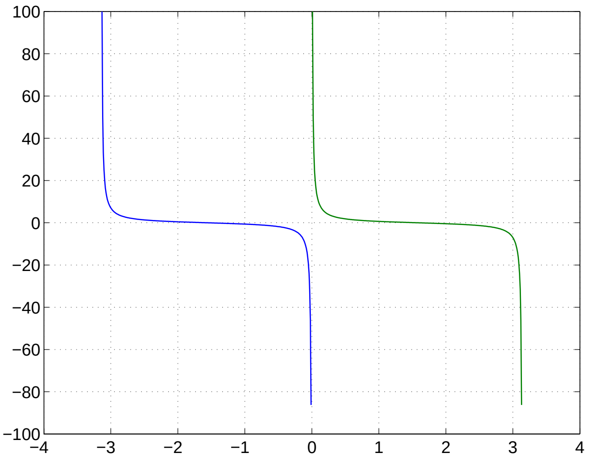
```
Y = cot(X)
```

Description The `cot` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

`Y = cot(X)` returns the cotangent for each element of `X`.

Examples Graph the cotangent the domains $-\pi < x < 0$ and $0 < x < \pi$.

```
x1 = -pi+0.01:0.01:-0.01;
x2 = 0.01:0.01:pi-0.01;
plot(x1,cot(x1),x2,cot(x2)), grid on
```



Definition The cotangent can be defined as

$$\cot(z) = \frac{1}{\tan(z)}$$

Algorithm `cot` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also acot, acoth, coth

Purpose Hyperbolic cotangent

Syntax

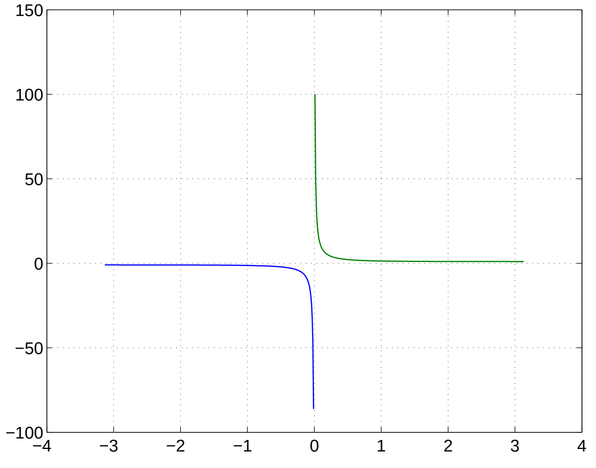
```
Y = coth(X)
```

Description The `coth` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

`Y = coth(X)` returns the hyperbolic cotangent for each element of `X`.

Examples Graph the hyperbolic cotangent over the domains $-\pi < x < 0$ and $0 < x < \pi$.

```
x1 = -pi+0.01:0.01:-0.01;
x2 = 0.01:0.01:pi-0.01;
plot(x1,coth(x1),x2,coth(x2)), grid on
```



Definition The hyperbolic cotangent can be defined as

$$\coth(z) = \frac{1}{\tanh(z)}$$

Algorithm `coth` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also `acot`, `acoth`, `cot`

Purpose

Covariance matrix

Syntax

```
C = cov(X)
C = cov(x,y)
```

Description

`C = cov(x)` where `x` is a vector returns the variance of the vector elements. For matrices where each row is an observation and each column a variable, `cov(x)` is the covariance matrix. `diag(cov(x))` is a vector of variances for each column, and `sqrt(diag(cov(x)))` is a vector of standard deviations.

`C = cov(x,y)`, where `x` and `y` are column vectors of equal length, is equivalent to `cov([x y])`.

Remarks

`cov` removes the mean from each column before calculating the result.

The *covariance* function is defined as

$$\mathrm{cov}(x_1, x_2) = E[(x_1 - \mu_1)(x_2 - \mu_2)]$$

where E is the mathematical expectation and $\mu_i = Ex_i$.

Examples

Consider `A = [-1 1 2 ; -2 3 1 ; 4 0 3]`. To obtain a vector of variances for each column of `A`:

```
v = diag(cov(A))'
v =
   10.3333    2.3333    1.0000
```

Compare vector `v` with covariance matrix `C`:

```
C =
   10.3333   -4.1667    3.0000
   -4.1667    2.3333   -1.5000
    3.0000   -1.5000    1.0000
```

The diagonal elements `C(i,i)` represent the variances for the columns of `A`. The off-diagonal elements `C(i,j)` represent the covariances of columns `i` and `j`.

See Also

`corrcoef`, `mean`, `std`

`xcorr`, `xcov` in the Signal Processing Toolbox

Purpose Sort complex numbers into complex conjugate pairs

Syntax

```
B = cplxpair(A)
B = cplxpair(A,tol)
B = cplxpair(A,[],dim)
B = cplxpair(A,tol,dim)
```

Description `B = cplxpair(A)` sorts the elements along different dimensions of a complex array, grouping together complex conjugate pairs.

The conjugate pairs are ordered by increasing real part. Within a pair, the element with negative imaginary part comes first. The purely real values are returned following all the complex pairs. The complex conjugate pairs are forced to be exact complex conjugates. A default tolerance of `100*eps` relative to `abs(A(i))` determines which numbers are real and which elements are paired complex conjugates.

If `A` is a vector, `cplxpair(A)` returns `A` with complex conjugate pairs grouped together.

If `A` is a matrix, `cplxpair(A)` returns `A` with its columns sorted and complex conjugates paired.

If `A` is a multidimensional array, `cplxpair(A)` treats the values along the first non-singleton dimension as vectors, returning an array of sorted elements.

`B = cplxpair(A,tol)` overrides the default tolerance.

`B = cplxpair(A,[],dim)` sorts `A` along the dimension specified by scalar dim.

`B = cplxpair(A,tol,dim)` sorts `A` along the specified dimension and overrides the default tolerance.

Diagnostics If there are an odd number of complex numbers, or if the complex numbers cannot be grouped into complex conjugate pairs within the tolerance, `cplxpair` generates the error message

```
Complex numbers can't be paired.
```

cputime

Purpose Elapsed CPU time

Syntax

```
cputime
```

Description `cputime` returns the total CPU time (in seconds) used by MATLAB from the time it was started. This number can overflow the internal representation and wrap around.

Examples The following code returns the CPU time used to run `surf(peaks(40))`.

```
t = cputime; surf(peaks(40)); e = cputime-t

e =
     0.4667
```

See Also `clock`, `etime`, `tic`, `toc`

Purpose Vector cross product

Syntax

```
C = cross(A,B)
C = cross(A,B,dim)
```

Description `C = cross(A,B)` returns the cross product of the vectors `A` and `B`. That is, `C = A x B`. `A` and `B` must be 3-element vectors. If `A` and `B` are multidimensional arrays, `cross` returns the cross product of `A` and `B` along the first dimension of length 3.

`C = cross(A,B,dim)` where `A` and `B` are multidimensional arrays, returns the cross product of `A` and `B` in dimension `dim` . `A` and `B` must have the same size, and both `size(A,dim)` and `size(B,dim)` must be 3.

Remarks To perform a dot (scalar) product of two vectors of the same size, use `c = dot(a,b)`.

Examples The cross and dot products of two vectors are calculated as shown:

```
a = [1 2 3];
b = [4 5 6];
c = cross(a,b)

c =
      -3     6    -3

d = dot(a,b)

d =
      32
```

See Also `dot`

Purpose Cosecant

Syntax

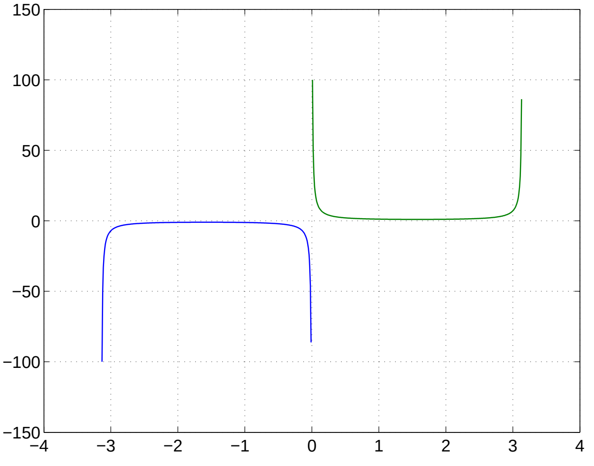
```
Y = csc(x)
```

Description The csc function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

`Y = csc(x)` returns the cosecant for each element of `x`.

Examples Graph the cosecant over the domains $-\pi < x < 0$ and $0 < x < \pi$.

```
x1 = -pi+0.01:0.01:-0.01;
x2 = 0.01:0.01:pi-0.01;
plot(x1,csc(x1),x2,csc(x2)), grid on
```



Definition The cosecant can be defined as

$$\csc(z) = \frac{1}{\sin(z)}$$

Algorithm csc uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also acsc, acsch, csch

Purpose Hyperbolic cosecant

Syntax

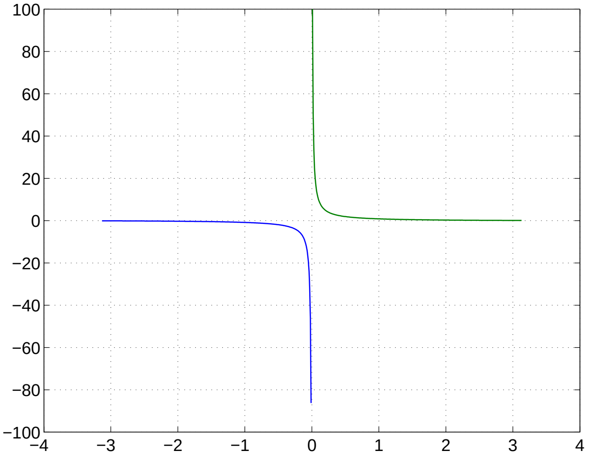
```
Y = csch(x)
```

Description The `csch` function operates element-wise on arrays. The function's domains and ranges include complex values. All angles are in radians.

`Y = csch(x)` returns the hyperbolic cosecant for each element of `x`.

Examples Graph the hyperbolic cosecant over the domains $-\pi < x < 0$ and $0 < x < \pi$.

```
x1 = -pi+0.01:0.01:-0.01;
x2 = 0.01:0.01:pi-0.01;
plot(x1,csch(x1),x2,csch(x2)), grid on
```



Definition The hyperbolic cosecant can be defined as

$$\operatorname{csch}(z) = \frac{1}{\sinh(z)}$$

Algorithm `csch` uses FDLIBM, which was developed at SunSoft, a Sun Microsystems, Inc. business, by Kwok C. Ng, and others. For information about FDLIBM, see `http://www.netlib.org`.

See Also acsc, acsch, csc

csvread

Purpose

Read a comma-separated value file

Syntax

```
M = csvread('filename')
M = csvread('filename',row,col)
M = csvread('filename',row,col,range)
```

Description

`M = csvread('filename')` reads a comma-separated value formatted file, `filename`. The result is returned in `M`. The file can only contain numeric values.

`M = csvread('filename',row,col)` reads data from the comma-separated value formatted file starting at the specified row and column. The row and column arguments are zero-based, so that `row=0` and `col=0` specifies the first value in the file.

`M = csvread('filename',row,col,range)` reads only the range specified. Specify the range using the notation, `[R1 C1 R2 C2]` where (`R1`,`C1`) is the upper-left corner of the data to be read and (`R2`,`C2`) is the lower-right corner. The range can also be specified using spreadsheet notation as in `range` = '`A1..B7`'.

Remarks

`csvread` fills empty delimited fields with zero. Data files having lines that end with a nonspace delimiter, such as a semicolon, produce a result that has an additional last column of zeros.

Examples

Given the file, `csvlist.dat` that contains the comma-separated values

```
02, 04, 06, 08, 10, 12
03, 06, 09, 12, 15, 18
05, 10, 15, 20, 25, 30
07, 14, 21, 28, 35, 42
11, 22, 33, 44, 55, 66
```

To read the entire file, use

```
csvread('csvlist.dat')

ans =

     2     4     6     8    10    12
     3     6     9    12    15    18
```

```
     5    10    15    20    25    30
     7    14    21    28    35    42
    11    22    33    44    55    66
```

To read the matrix starting with zero-based row 2, column 0 and assign it to the variable, `m`,

```
m = csvread('csvlist.dat', 2, 0)

m =

     5    10    15    20    25    30
     7    14    21    28    35    42
    11    22    33    44    55    66
```

To read the matrix bounded by zero-based (2,0) and (3,3) and assign it to `m`,

```
m = csvread('csvlist.dat', 2, 0, [2,0,3,3])

m =

     5    10    15    20
     7    14    21    28
```

See Also `csvwrite`, `dlmread`, `textread`, `wk1read`, `file formats`, `importdata`, `uiimport`

csvwrite

Purpose Write a comma-separated value file

Syntax

```
csvwrite('filename',M)
csvwrite('filename',M,row,col)
```

Description `csvwrite('filename',M)` writes matrix `M` into `filename` as comma-separated values.

`csvwrite('filename',M,row,col)` writes matrix `M` into `filename` starting at the specified row and column offset. The row and column arguments are zero-based, so that `row=0` and `C=0` specifies the first value in the file.

Examples The following example creates a comma-separated value file from the matrix, `m`.

```
m = [3 6 9 12 15; 5 10 15 20 25; 7 14 21 28 35; 11 22 33 44 55];

csvwrite('csvlist.dat',m)
type csvlist.dat

3,6,9,12,15
5,10,15,20,25
7,14,21,28,35
11,22,33,44,55
```

The next example writes the matrix to the file, starting at a column offset of `2`.

```
csvwrite('csvlist.dat',m,0,2)
type csvlist.dat

,,3,6,9,12,15
,,5,10,15,20,25
,,7,14,21,28,35
,,11,22,33,44,55
```

See Also `csvread`, `dlmwrite`, `textread`, `wk1write`, `file formats`, `importdata`, `uiimport`

Purpose

Cumulative product

Syntax

```
B = cumprod(A)
B = cumprod(A,dim)
```

Description

`B = cumprod(A)` returns the cumulative product along different dimensions of an array.

If `A` is a vector, `cumprod(A)` returns a vector containing the cumulative product of the elements of `A`.

If `A` is a matrix, `cumprod(A)` returns a matrix the same size as `A` containing the cumulative products for each column of `A`.

If `A` is a multidimensional array, `cumprod(A)` works on the first nonsingleton dimension.

`B = cumprod(A,dim)` returns the cumulative product of the elements along the dimension of `A` specified by scalar `dim`. For example, `cumprod(A,1)` increments the first (row) index, thus working along the rows of `A`.

Examples

```
cumprod(1:5)
ans =
     1   2   6   24   120

A = [1 2 3; 4 5 6];

cumprod(A)
ans =
     1     2     3
     4    10    18

cumprod(A,2)
ans =
     1     2     6
     4    20   120
```

See Also

`cumsum`, `prod`, `sum`

cumsum

Purpose Cumulative sum

Syntax

```
B = cumsum(A)
B = cumsum(A,dim)
```

Description `B = cumsum(A)` returns the cumulative sum along different dimensions of an array.

If `A` is a vector, `cumsum(A)` returns a vector containing the cumulative sum of the elements of `A`.

If `A` is a matrix, `cumsum(A)` returns a matrix the same size as `A` containing the cumulative sums for each column of `A`.

If `A` is a multidimensional array, `cumsum(A)` works on the first nonsingleton dimension.

`B = cumsum(A,dim)` returns the cumulative sum of the elements along the dimension of `A` specified by scalar `dim`. For example, `cumsum(A,1)` works across the first dimension (the rows).

Examples

```
cumsum(1:5)
ans =
       [1  3  6  10  15]

A = [1 2 3; 4 5 6];

cumsum(A)
ans =
       1     2     3
       5     7     9

cumsum(A,2)
ans =
       1     3     6
       4     9    15
```

See Also `cumprod`, `prod`, `sum`

Purpose Cumulative trapezoidal numerical integration

Syntax

```
Z = cumtrapz(Y)
Z = cumtrapz(X,Y)
Z = cumtrapz(... dim)
```

Description

`Z = cumtrapz(Y)` computes an approximation of the cumulative integral of `Y` via the trapezoidal method with unit spacing. To compute the integral with other than unit spacing, multiply `Z` by the spacing increment.

For vectors, `cumtrapz(Y)` is a vector containing the cumulative integral of `Y`.

For matrices, `cumtrapz(Y)` is a matrix the same size as `Y` with the cumulative integral over each column.

For multidimensional arrays, `cumtrapz(Y)` works across the first nonsingleton dimension.

`Z = cumtrapz(X,Y)` computes the cumulative integral of `Y` with respect to `X` using trapezoidal integration. `X` and `Y` must be vectors of the same length, or `X` must be a column vector and `Y` an array whose first nonsingleton dimension is `length(X)`. `cumtrapz` operates across this dimension.

If `X` is a column vector and `Y` an array whose first nonsingleton dimension is `length(X)`, `cumtrapz(X,Y)` operates across this dimension.

`Z = cumtrapz(X,Y,dim) or cumtrapz(Y,DIM)` integrates across the dimension of `Y` specified by scalar `dim`. The length of `X` must be the same as `size(Y,dim)`.

Example

```
Y = [0 1 2; 3 4 5];

cumtrapz(Y,1)
ans =
         0         0         0
    1.5000    2.5000    3.5000

cumtrapz(Y,2)
ans =
         0    0.5000    2.0000
         0    3.5000    8.0000
```

See Also

`cumsum`, `trapz`

Purpose Computes the curl and angular velocity of a vector field

Syntax

```
[curlx,curly,curlz,cav] = curl(X,Y,Z,U,V,W)
[curlx,curly,curlz,cav] = curl(U,V,W)
[curlz,cav]= curl(X,Y,U,V)
[curlz,cav]= curl(U,V)
[curlx,curly,curlz] = curl(...), [curlx,curly] = curl(...)
cav = curl(...)
```

Description `[curlx,curly,curlz,cav] = curl(X,Y,Z,U,V,W)` computes the curl and angular velocity perpendicular to the flow (in radians per time unit) of a 3-D vector field `U`, `V`, `W`. The arrays `X`, `Y`, `Z` define the coordinates for `U`, `V`, `W` and must be monotonic and 3-D plaid (as if produced by `meshgrid`).

`[curlx,curly,curlz,cav] = curl(U,V,W)` assumes `X`, `Y`, and `Z` are determined by the expression:

```
[X Y Z] = meshgrid(1:n,1:m,1:p)
```

where `[m,n,p] = size(U)`.

`[curlz,cav]= curl(X,Y,U,V)` computes the curl `z`-component and the angular velocity perpendicular to `z` (in radians per time unit) of a 2-D vector field `U`, `V`. The arrays `X`, `Y` define the coordinates for `U`, `V` and must be monotonic and 2-D plaid (as if produced by `meshgrid`).

`[curlz,cav]= curl(U,V)` assumes `X` and `Y` are determined by the expression:

```
[X Y] = meshgrid(1:n,1:m)
```

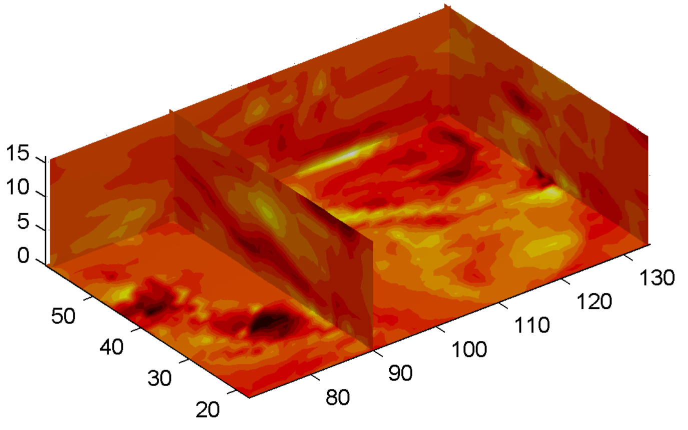
where `[m,n] = size(U)`.

`[curlx,curly,curlz] = curl(...), curlx,curly] = curl(...)` returns only the curl.

`cav = curl(...)` returns only the curl angular velocity.

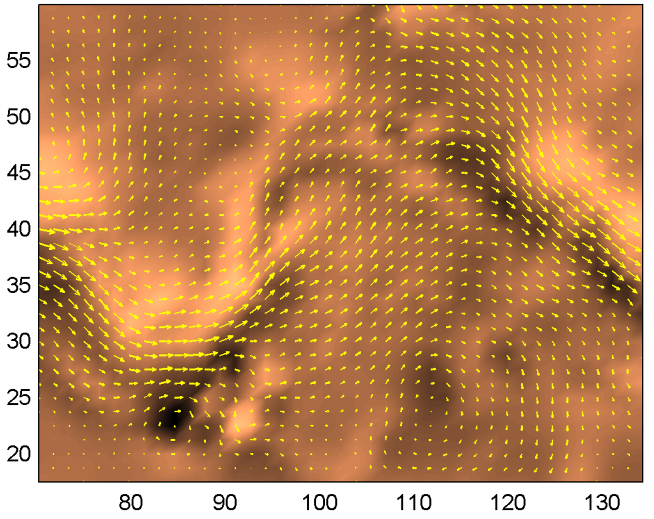
Examples This example uses colored slice planes to display the curl angular velocity at specified locations in the vector field.

```
load wind
cav = curl(x,y,z,u,v,w);
slice(x,y,z,cav,[90 134],[59],[0]);
shading interp
daspect([1 1 1]); axis tight
colormap hot(16)
camlight
```



This example views the curl angular velocity in one plane of the volume and plots the velocity vectors (quiver) in the same plane.

```
load wind
k = 4;
x = x(:,:,k); y = y(:,:,k); u = u(:,:,k); v = v(:,:,k);
cav = curl(x,y,u,v);
pcolor(x,y,cav); shading interp
hold on;
quiver(x,y,u,v,'y')
hold off
colormap copper
```



See Also

`streamribbon`, `divergence`

"Volume Visualization" for related functions

Displaying Curl with Stream Ribbons for another example

customverctrl

Purpose

Allow custom source control system

Syntax

```
customverctrl(filename, arguments)
```

Description

This function is supplied for customers who want to integrate a version control system that is not supported with MATLAB. This function must conform to the structure of one of the supported version control systems, for example RCS. See the files `clearcase.m`, `pvcs.m`, `rcs.m`, and `sourcesafe.m` in `$matlabroot\toolbox\matlab\verctrl` as examples.

See Also

`checkin`, `checkout`, `cmopts`, `undocheckout`

Purpose

Generate cylinder

Syntax

```
[X,Y,Z] = cylinder
[X,Y,Z] = cylinder(r)
[X,Y,Z] = cylinder(r,n)
cylinder(...)
```

Description

`cylinder` generates *x*, *y*, and *z* coordinates of a unit cylinder. You can draw the cylindrical object using `surf` or `mesh`, or draw it immediately by not providing output arguments.

`[X,Y,Z] = cylinder` returns the *x*, *y*, and *z* coordinates of a cylinder with a radius equal to `1`. The cylinder has 20 equally spaced points around its circumference.

`[X,Y,Z] = cylinder(r)` returns the *x*, *y*, and *z* coordinates of a cylinder using `r` to define a profile curve. `cylinder` treats each element in `r` as a radius at equally spaced heights along the unit height of the cylinder. The cylinder has 20 equally spaced points around its circumference.

`[X,Y,Z] = cylinder(r,n)` returns the *x*, *y*, and *z* coordinates of a cylinder based on the profile curve defined by vector `r`. The cylinder has `n` equally spaced points around its circumference.

`cylinder(...)`, with no output arguments, plots the cylinder using `surf`.

Remarks

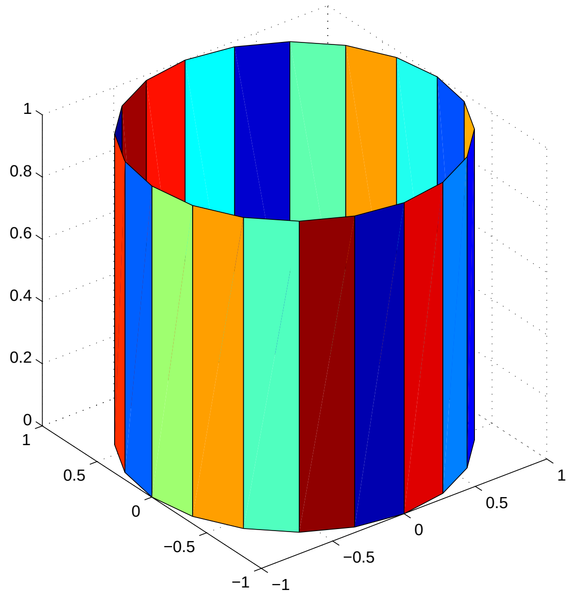
`cylinder` treats its first argument as a profile curve. The resulting surface graphics object is generated by rotating the curve about the *x*-axis, and then aligning it with the *z*-axis.

Examples

Create a cylinder with randomly colored faces.

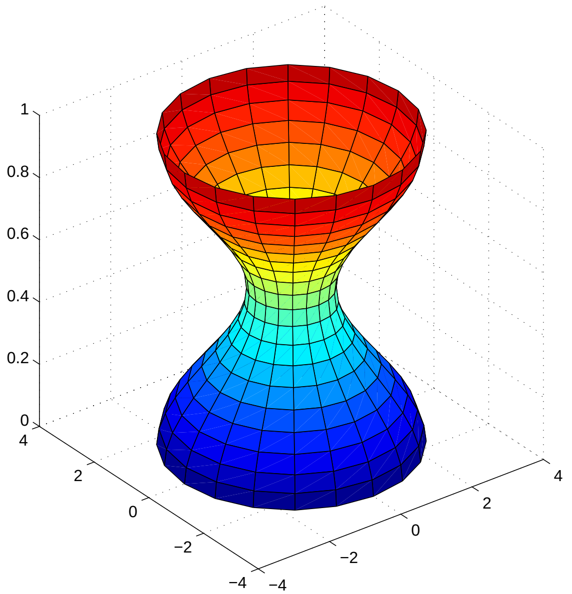
```
cylinder
axis square
h = findobj('Type','surface');
```

```
set(h,'CData',rand(size(get(h,'CData'))))
```



Generate a cylinder defined by the profile function `2+sin(t)`.

```
t = 0:pi/10:2*pi;
[X,Y,Z] = cylinder(2+cos(t));
surf(X,Y,Z)
axis square
```



See Also `sphere`, `surf`

"Polygons and Surfaces" for related functions

daspect

Purpose Set or query the axes data aspect ratio

Syntax

```
daspect
daspect([aspect_ratio])
daspect('mode')
daspect('auto')
daspect('manual')
daspect(axes_handle,...)
```

Description The data aspect ratio determines the relative scaling of the data units along the *x*-, *y*-, and *z*-axes.

`daspect` with no arguments returns the data aspect ratio of the current axes.

`daspect([aspect_ratio])` sets the data aspect ratio in the current axes to the specified value. Specify the aspect ratio as three relative values representing the ratio of the *x*-, *y*-, and *z*-axis scaling (e.g., `[1 1 3]` means one unit in *x* is equal in length to one unit in *y* and three unit in *z*).

`daspect('mode')` returns the current value of the data aspect ratio mode, which can be either `auto` (the default) or `manual`. See Remarks.

`daspect('auto')` sets the data aspect ratio mode to `auto`.

`daspect('manual')` sets the data aspect ratio mode to `manual`.

`daspect(axes_handle,...)` performs the set or query on the axes identified by the first argument, `axes_handle`. When you do not specify an axes handle, `daspect` operates on the current axes.

Remarks `daspect` sets or queries values of the axes object `DataAspectRatio` and `DataAspectRatioMode` properties.

When the data aspect ratio mode is `auto`, MATLAB adjusts the data aspect ratio so that each axis spans the space available in the figure window. If you are displaying a representation of a real-life object, you should set the data aspect ratio to `[1 1 1]` to produce the correct proportions.

Setting a value for data aspect ratio or setting the data aspect ratio mode to `manual` disables the MATLAB stretch-to-fill feature (stretching of the axes to fit the window). This means setting the data aspect ratio to a value, including its current value,

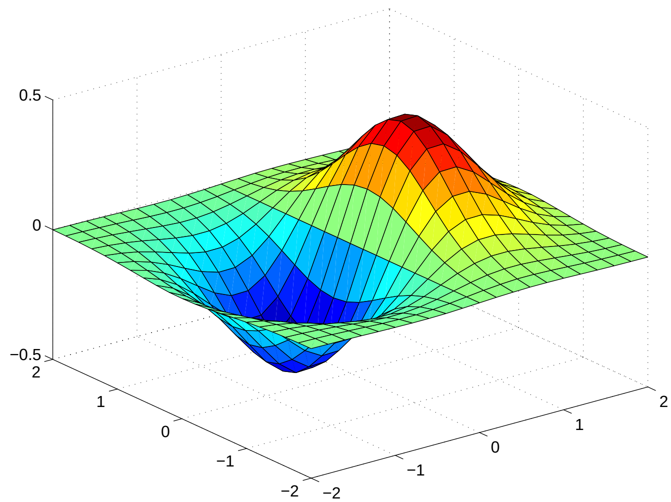
```
daspect(daspect)
```

can cause a change in the way the graphs look. See the Remarks section of the axes description for more information.

Examples

The following surface plot of the function $z = xe^{(-x^2 - y^2)}$ is useful to illustrate the data aspect ratio. First plot the function over the range $-2 \le x \le 2$, $-2 \le y \le 2$,

```
[x,y] = meshgrid([-2:.2:2]);
z = x.*exp(-x.^2 - y.^2);
surf(x,y,z)
```

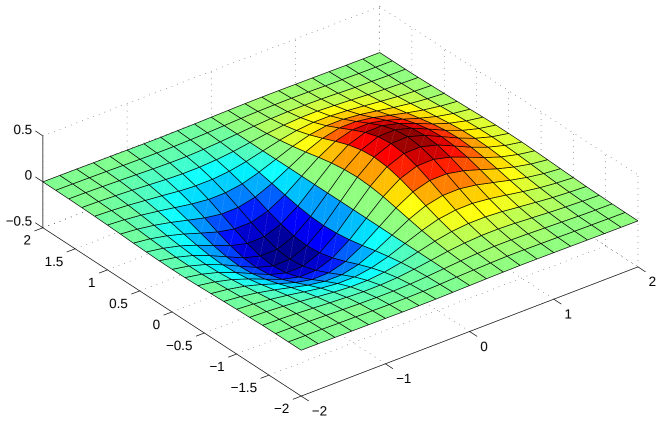


Querying the data aspect ratio shows how MATLAB has drawn the surface.

```
daspect
ans =
     4   4   1
```

Setting the data aspect ratio to `[1 1 1]` produces a surface plot with equal scaling along each axis.

```
daspect([1 1 1])
```



See Also

axis, pbaspect, xlim, ylim, zlim

The axes properties DataAspectRatio, PlotBoxAspectRatio, XLim, YLim, ZLim

"Setting the Aspect Ratio and Axis Limits" for related functions

Axes Aspect Ratio for more information.

Purpose Current date string

Syntax `str = date`

Description `str = date` returns a string containing the date in `dd-mmm-yyyy` format.

See Also `clock`, `datenum`, `now`

datenum

Purpose Serial date number

Syntax

```
N = datenum(DT)
N = datenum(DT,P)
N = datenum(Y,M,D)
N = datenum(Y,M,D,H,MI,S)
```

Description The `datenum` function converts date strings and date vectors (defined by `datevec`) into serial date numbers. Date numbers are serial days elapsed from some reference date. By default, the serial day 1 corresponds to 1-Jan-0000.

`N = datenum(DT)` converts the date string or date vector `DT` into a serial date number. Date strings with two-character years, e.g., `12-june-12`, are assumed to lie within the 100-year period centered about the current year.

Note If `DT` is a string, it must be in one of the date formats `0`, `1`, `2`, `6`, `13`, `14`, `15`, `16`, or `23` as defined by `datestr`.

`N = datenum(DT,P)` uses the specified pivot year as the starting year of the 100-year range in which a two-character year resides. The default pivot year is the current year minus 50 years.

`N = datenum(Y,M,D)` returns the serial date number for corresponding elements of the `Y`, `M`, and `D` (year, month, day) arrays. `Y`, `M`, and `D` must be arrays of the same size (or any can be a scalar). Values outside the normal range of each array are automatically "carried" to the next unit.

`N = datenum(Y,M,D,H,MI,S)` returns the serial date number for corresponding elements of the `Y`, `M`, `D`, `H`, `MI`, and `S` (year, month, day, hour, minute, and second) array values. `Y`, `M`, `D`, `H`, `MI`, and `S` must be arrays of the same size (or any can be a scalar). Values outside the normal range of each array are automatically carried to the next unit (for example month values greater than 12 are carried to years). Month values less than 1 are set to be 1. All other units can wrap and have valid negative values.

Examples

Convert a date string to a serial date number.

```
n = datenum('19-May-2001')

n =
      730990
```

Specifying year, month, and day, convert a date to a serial date number.

```
n = datenum(2001,12,19)

n =
      731204
```

Convert a date vector to a serial date number.

```
format bank
n = datenum([2001 5 19 18 0 0])

n =
  730990.75
```

Convert a date string to a serial date number using the default pivot year

```
n = datenum('12-june-12')

n =
      735032
```

Convert the same date string to a serial date number using 1900 as the pivot year.

```
n = datenum('12-june-12', 1900)

n =
      698507
```

See Also

`datestr`, `datevec`, `now`

datestr

Purpose Date string format

Syntax

```
str = datestr(DT,dateform)
str = datestr(DT,dateform,P)
```

Description The `datestr` function converts serial date numbers (defined by `datenum`) and date vectors (defined by `datevec`) into date strings.

`str = datestr(DT,dateform)` converts a single date vector, or each element of an array of serial date numbers to a date string. Date strings with two-character years, e.g., `12-june-12`, are assumed to lie within the 100-year period centered about the current year.

`str = datestr(DT,dateform,P)` uses the specified pivot year as the starting year of the 100-year range in which a two-character year resides. The default pivot year is the current year minus 50 years.

The optional argument `dateform` specifies the date format of the result. `dateform` can be either a number or a string:

`dateform` **(number)**	`dateform` **(string)**	**Example**
0	'dd-mmm-yyyy HH:MM:SS'	01-Mar-2000 15:45:17
1	'dd-mmm-yyyy'	01-Mar-2000
2	'mm/dd/yy'	03/01/00
3	'mmm'	Mar
4	'm'	M
5	'mm'	03
6	'mm/dd'	03/01
7	'dd'	01
8	'ddd'	Wed
9	'd'	W

dateform (number)	dateform (string)	Example
10	'yyyy'	2000
11	'yy'	00
12	'mmmyy'	Mar00
13	'HH:MM:SS'	15:45:17
14	'HH:MM:SS PM'	3:45:17 PM
15	'HH:MM'	15:45
16	'HH:MM PM'	3:45 PM
17	'QQ-YY'	Q1-01
18	'QQ'	Q1
19	'dd/mm'	01/03
20	'dd/mm/yy'	01/03/00
21	'mmm.dd.yyyy HH:MM:SS'	Mar.01,2000 15:45:17
22	'mmm.dd.yyyy'	Mar.01.2000
23	'mm/dd/yyyy'	03/01/2000
24	'dd/mm/yyyy'	01/03/2000
25	'yy/mm/dd'	00/03/01
26	'yyyy/mm/dd'	2000/03/01
27	'QQ-YYYY’	Q1-2001
28	'mmmyyyy'	Mar2000
29 (ISO 8601)	'yyyy-mm-dd'	2000-03-01
30 (ISO 8601)	'yyyymmddTHHMMSS'	20000301T154517
31	'yyyy-mm-dd HH:MM:SS'	2000-03-01 15:45:17

NOTE `dateform` numbers `0`, `1`, `2`, `6`, `13`, `14`, `15`, `16`, and `23` produce a string suitable for input to `datenum` or `datevec`. Other date string formats will not work with these functions.

Time formats like `'h:m:s'`, `'h:m:s.s'`, `'h:m pm'`, ... can also be part of the input array `DT`. If you do not specify `dateform`, or if you specify `dateform` as `-1`, the date string format defaults to

1	if `DT` contains date information only, e.g., 01-Mar-1995
16	if `DT` contains time information only e.g., 03:45 PM
0	if `DT` is a date vector, or a string that contains both date and time information e.g., 01-Mar-1995 03:45

See Also

`date`, `datetick`, `datenum`, `datevec`

Purpose Label tick lines using dates

Syntax

```
datetick(tickaxis)
datetick(tickaxis,dateform)
```

Description `datetick(tickaxis)` labels the tick lines of an axis using dates, replacing the default numeric labels. `tickaxis` is the string `'x'`, `'y'`, or `'z'`. The default is `'x'`. `datetick` selects a label format based on the minimum and maximum limits of the specified axis.

`datetick(tickaxis,`*`dateform`*`)` formats the labels according to the integer *`dateform`* (see table). To produce correct results, the data for the specified axis must be serial date numbers (as produced by `datenum`).

dateform **(number)**	*dateform* **(string)**	**Example**
0	'dd-mmm-yyyy HH:MM:SS'	01-Mar-2000 15:45:17
1	'dd-mmm-yyyy'	01-Mar-2000
2	'mm/dd/yy'	03/01/00
3	'mmm'	Mar
4	'm'	M
5	'mm'	03
6	'mm/dd'	03/01
7	'dd'	01
8	'ddd'	Wed
9	'd'	W
10	'yyyy'	2000
11	'yy'	00
12	'mmmyy'	Mar00
13	'HH:MM:SS'	15:45:17

dateform (number)	*dateform* (string)	Example
14	'HH:MM:SS PM'	3:45:17 PM
15	'HH:MM'	15:45
16	'HH:MM PM'	3:45 PM
17	'QQ-YY'	Q1–01
18	'QQ'	Q1
19	'dd/mm'	01/03
20	'dd/mm/yy'	01/03/00
21	'mmm.dd.yyyy HH:MM:SS'	Mar.01,2000 15:45:17
22	'mmm.dd.yyyy'	Mar.01.2000
23	'mm/dd/yyyy'	03/01/2000
24	'dd/mm/yyyy'	01/03/2000
25	'yy/mm/dd'	00/03/01
26	'yyyy/mm/dd'	2000/03/01
27	'QQ-YYYY’	Q1-2001
28	'mmmyyyy'	Mar2000

Remarks

`datetick` calls `datestr` to convert date numbers to date strings.

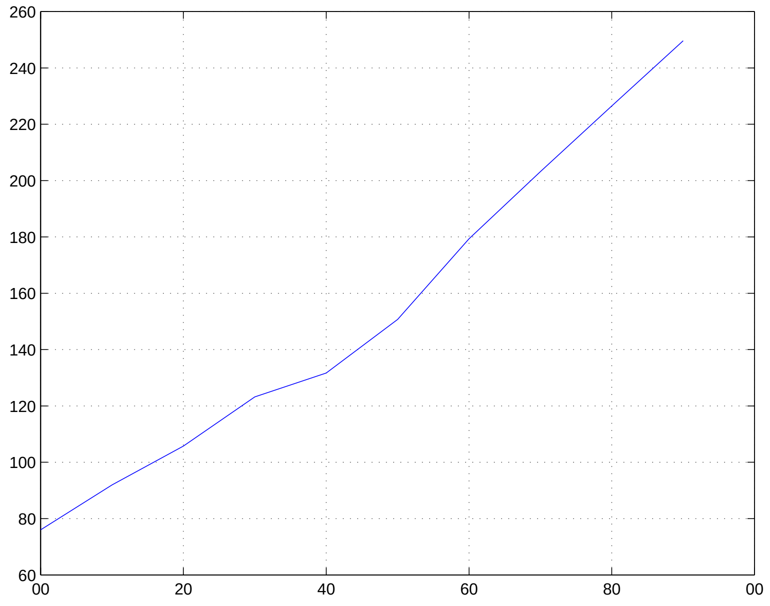
To change the tick spacing and locations, set the appropriate axes property (i.e., `XTick`, `YTick`, or `ZTick`) before calling `datetick`.

Example

Consider graphing population data based on the 1990 U.S. census:

```
t = (1900:10:1990)';   % Time interval
p = [75.995 91.972 105.711 123.203 131.669 ...
    150.697 179.323 203.212 226.505 249.633]';  % Population
plot(datenum(t,1,1),p) % Convert years to date numbers and plot
grid on
```

```
datetick('x',11)    % Replace x-axis ticks with 2-digit year labels
```



See Also

The axes properties `XTick`, `YTick`, and `ZTick`.

`datenum`, `datestr`

"Annotating Plots" for related functions

datevec

Purpose

Date components

```
C = datevec(A)
C = datevec(A,P)
[Y,M,D,H,MI,S] = datevec(A)
```

Description

`C = datevec(A)` splits its input into an n-by-6 array with each row containing the vector `[Y,M,D,H,MI,S]`. The first five date vector elements are integers. Input `A` can either consist of strings of the sort produced by the `datestr` function, or scalars of the sort produced by the `datenum` and `now` functions. Date strings with two-character years, e.g., `12-june-12`, are assumed to lie within the 100-year period centered about the current year.

`C = datevec(A,P)` uses the specified pivot year as the starting year of the 100-year range in which a two-character year resides. The default pivot year is the current year minus 50 years.

`[Y,M,D,H,MI,S] = datevec(A)` returns the components of the date vector as individual variables.

When creating your own date vector, you need not make the components integers. Any components that lie outside their conventional ranges affect the next higher component (so that, for instance, the anomalous June 31 becomes July 1). A zeroth month, with zero days, is allowed.

Examples

An example of using a string as input:

```
datevec('12/24/1984')

ans =
        1984          12          24           0           0           0
```

An example of using a serial date number as input:

```
t = datenum('12/24/1984')

t =
    725000

datevec(t)
```

```
ans =
       1984        12        24         0         0         0
```

See Also clock, datenum, datestr, now

dbclear

Purpose Clear breakpoints

Graphical Interface As an alternative to the `dbclear` function, there are various ways to clear breakpoints using the Editor/Debugger.

Syntax

```
dbclear all
dbclear all in mfile
dbclear in mfile
dbclear in mfile at lineno
dbclear in mfile at subfun
dbclear if error
dbclear if warning
dbclear if naninf
dbclear if infnan
```

Description

`dbclear all` removes all breakpoints in all M-files, as well as pauses set for error, warning, and `naninf/infnan` using `dbstop`.

`dbclear all in mfile` removes breakpoints in `mfile`.

`dbclear in mfile` removes the breakpoint set at the first executable line in `mfile`.

`dbclear in mfile at lineno` removes the breakpoint set at the line number `lineno` in `mfile`.

`dbclear in mfile at subfun` removes the breakpoint set at the subfunction `subfun` in `mfile`.

`dbclear if error` removes the pause set using `dbstop if error`.

`dbclear if warning` removes the pause set using `dbstop if warning`.

`dbclear if naninf` removes the pause set using `dbstop if naninf`.

`dbclear if infnan` removes the pause set using `dbstop if infnan`.

Remarks The `at`, `in`, and `if` keywords, familiar to users of the UNIX debugger dbx, are optional.

See Also

`dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`, `partialpath`

dbcont

Purpose

Resume execution

Graphical Interface

As an alternative to the `dbcont` function, you can select **Continue** from the **Debug** menu in the Editor/Debugger.

Syntax

```
dbcont
```

Description

`dbcont` resumes execution of an M-file from a breakpoint. Execution continues until another breakpoint is encountered, an error occurs, or MATLAB returns to the base workspace prompt.

See Also

`dbclear`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

Purpose Change local workspace context

Graphical Interface As an alternative to the `dbdown` function, you can select a different workspace from the **Stack** field in the Editor/Debugger toolbar.

Syntax

```
dbdown
```

Description `dbdown` changes the current workspace context to the workspace of the called M-file when a breakpoint is encountered. You must have issued the `dbup` function at least once before you issue this function. `dbdown` is the opposite of `dbup`.

Multiple `dbdown` functions change the workspace context to each successively executed M-file on the stack until the current workspace context is the current breakpoint. It is not necessary, however, to move back to the current breakpoint to continue execution or to step to the next line.

See Also `dbclear`, `dbcont`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

dblquad

Purpose Numerically evaluate double integral

Syntax

```
q = dblquad(fun,xmin,xmax,ymin,ymax)
q = dblquad(fun,xmin,xmax,ymin,ymax,tol)
q = dblquad(fun,xmin,xmax,ymin,ymax,tol,method)
q = dblquad(fun,xmin,xmax,ymin,ymax,tol,method,p1,p2,...)
```

Description

`q = dblquad(fun,xmin,xmax,ymin,ymax)` calls the quad function to evaluate the double integral `fun(x,y)` over the rectangle `xmin <= x <= xmax`, `ymin <= y <= ymax`. `fun(x,y)` must accept a vector `x` and a scalar `y` and return a vector of values of the integrand.

`q = dblquad(fun,xmin,xmax,ymin,ymax,tol)` uses a tolerance tol instead of the default, which is `1.0e-6`.

`q = dblquad(fun,xmin,xmax,ymin,ymax,tol,method)` uses the quadrature function specified as `method`, instead of the default `quad`. Valid values for `method` are `@quadl` or the function handle of a user-defined quadrature method that has the same calling sequence as `quad` and `quadl`.

`dblquad(fun,xmin,xmax,ymin,ymax,tol,method,p1,p2,...)` passes the additional parameters `p1,p2,...` to `fun(x,y,p1,p2,...)`. Use `[]` as a placeholder if you do not specify `tol` or `method`. `dblquad(fun,xmin,xmax,ymin,ymax,[],[],p1,p2,...)` is the same as `dblquad(fun,xmin,xmax,ymin,ymax,1.e-6,@quad,p1,p2,...)`

Example

`fun` can be an inline object

```
Q = dblquad(inline('y*sin(x)+x*cos(y)'), pi, 2*pi, 0, pi)
```

or a function handle

```
Q = dblquad(@integrnd, pi, 2*pi, 0, pi)
```

where `integrnd.m` is an M-file.

```
function z = integrnd(x, y)
z = y*sin(x)+x*cos(y);
```

The `integrnd` function integrates `y*sin(x)+x*cos(y)` over the square `pi <= x <= 2*pi`, `0 <= y <= pi`. Note that the integrand can be evaluated with a vector `x` and a scalar `y` .

Nonsquare regions can be handled by setting the integrand to zero outside of the region. For example, the volume of a hemisphere is

```
dblquad(inline('sqrt(max(1-(x.^2+y.^2),0))'),-1,1,-1,1)
```

or

```
dblquad(inline('sqrt(1-(x.^2+y.^2)).*(x.^2+y.^2<=1)'),-1,1,-1,1
)
```

See Also

`inline`, `quad`, `quadl`, `triplequad`, `@` (function handle)

dbmex

Purpose Enable MEX-file debugging

Syntax

```
dbmex on
dbmex off
dbmex stop
dbmex print
```

Description `dbmex` **`on`** enables MEX-file debugging for UNIX platforms. It is not supported on the Sun Solaris platform. To use this option, first start MATLAB from within a debugger by typing: `matlab -Ddebugger`, where `debugger` is the name of the debugger.

`dbmex` **`off`** disables MEX-file debugging.

`dbmex` **`stop`** returns to the debugger prompt.

`dbmex` **`print`** displays MEX-file debugging information.

Remarks On Sun Solaris platforms, `dbmex` is not supported. See the Technical Support solution 23388 at `http://www.mathworks.com/support/solutions/data/23388.shtml` for an alternative method of debugging.

See Also `dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

Purpose Quit debug mode

Graphical Interface As an alternative to the `dbquit` function, you can select **Exit Debug Mode** from the **Debug** menu in the Editor/Debugger.

Syntax

```
dbquit
```

Description `dbquit` immediately terminates the debugger and returns control to the base workspace prompt. The M-file being processed is *not* completed and no results are returned.

All breakpoints remain in effect.

See Also `dbclear`, `dbcont`, `dbdown`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

dbstack

Purpose

Display function call stack

Graphical Interface

As an alternative to the `dbstack` function, you can view the **Stack** field in the Editor/Debugger toolbar.

Syntax

```
dbstack
[ST,I] = dbstack
```

Description

`dbstack` displays the line numbers and M-file names of the function calls that led to the current breakpoint, listed in the order in which they were executed. The line number of the most recently executed function call (at which the current breakpoint occurred) is listed first, followed by its calling function, which is followed by its calling function, and so on, until the topmost M-file function is reached.

`[ST,I] = dbstack` returns the stack trace information in an `m`-by-`1` structure `ST` with the fields

`name`	Function name
`line`	Function line number

The current workspace index is returned in `I`.

Examples

```
dbstack

In /usr/local/matlab/toolbox/matlab/cond.m at line 13
  In test1.m at line 2
  In test.m at line 3
```

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`, `dbup`

Purpose

List all breakpoints

Graphical Interface

As an alternative to the `dbstatus` function, you can see breakpoint icons for a file that is open in the Editor/Debugger.

Syntax

```
dbstatus
dbstatus function
s = dbstatus(...)
```

Description

`dbstatus` lists all breakpoints in effect including `error`, `warning`, and `naninf`.

`dbstatus function` displays a list of the line numbers for which breakpoints are set in the specified M-file.

`s = dbstatus(...)` returns the breakpoint information in an `m`-by-`1` structure with the fields

`name`	Function name
`line`	Function line number
`cond`	Condition string (`error`, `warning`, or `naninf`)

Use `dbstatus class/function` or `dbstatus private/function` or `dbstatus class/private/function` to determine the status for methods, private functions, or private methods (for a class named `class`). In all these forms you can further qualify the function name with a subfunction name as in `dbstatus function/subfunction`.

See Also

`dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstep`, `dbstop`, `dbtype`, `dbup`

dbstep

Purpose Execute one or more lines from current breakpoint

Graphical Interface As an alternative to the `dbstep` function, you can select **Step** or **Step In** from the **Debug** menu in the Editor/Debugger.

Syntax

```
dbstep
dbstep nlines
dbstep in
```

Description This function allows you to debug an M-file by following its execution from the current breakpoint. At a breakpoint, the `dbstep` function steps through execution of the current M-file one line at a time or at the rate specified by `nlines`.

`dbstep`, by itself, executes the next executable line of the current M-file. `dbstep` steps over the current line, skipping any breakpoints set in functions called by that line.

`dbstep nlines` executes the specified number of executable lines.

`dbstep in` steps to the next executable line. If that line contains a call to another M-file, execution resumes with the first executable line of the called file. If there is no call to an M-file on that line, `dbstep in` is the same as `dbstep`.

See Also `dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstop`, `dbtype`, `dbup`

Purpose

Set breakpoints in M-file function

Graphical Interface

As an alternative to the `dbstop` function, you can use the **Breakpoints** menu or the breakpoint alley in the Editor/Debugger.

Syntax

```
dbstop in mfile
dbstop in mfile at lineno
dbstop in mfile at subfun
dbstop if error
dbstop if all error
dbstop if warning
dbstop if naninf
dbstop if infnan
```

Description

`dbstop in mfile` temporarily stops execution of `mfile` when you run it, at the first executable line, putting MATLAB in debug mode. `mfile` must be in a directory that is on the search path or in the current directory. If you have graphical debugging enabled, the MATLAB Debugger opens with a breakpoint at the first executable line of `mfile`. You can then use the debugging utilities, review the workspace, or issue any valid MATLAB function. Use `dbcont` or `dbstep` to resume execution of `mfile`. Use `dbquit` to exit from the Debugger.

`dbstop in mfile at lineno` temporarily stops execution of `mfile` when you run it, just prior to execution of the line whose number is `lineno`, putting MATLAB in debug mode. `mfile` must be in a directory that is on the search path or in the current directory. If you have graphical debugging enabled, the MATLAB Debugger opens `mfile` with a breakpoint at line `lineno`. If that line is not executable, execution stops and the breakpoint is set at the next executable line following `lineno`. When execution stops, you can use the debugging utilities, review the workspace, or issue any valid MATLAB function. Use `dbcont` or `dbstep` to resume execution of `mfile`. Use `dbquit` to exit from the Debugger.

`dbstop in mfile at subfun` temporarily stops execution of `mfile` when you run it, just prior to execution of the subfunction `subfun`, putting MATLAB in debug mode. `mfile` must be in a directory that is on the search path or in the current directory. If you have graphical debugging enabled, the MATLAB Debugger opens `mfile` with a breakpoint at the subfunction specified by `subfun`. You can then use the debugging utilities, review the workspace, or issue any valid MATLAB function. Use `dbcont` or `dbstep` to resume execution of `mfile`. Use `dbquit` to exit from the Debugger.

`dbstop if error` stops execution when any M-file you subsequently run produces a run-time error, putting MATLAB in debug mode, paused at the line that generated the error. The M-file must be in a directory that is on the search path or in the current directory. The errors that stop execution do not include run-time errors that are detected within a `try...catch` block. You cannot resume execution after an error. Use `dbquit` to exit from the Debugger.

`dbstop if all error` is the same as `dbstop if error`, except that it stops execution on any type of run-time error, including errors that are detected within a `try...catch` block.

`dbstop if warning` stops execution when any M-file you subsequently run produces a run-time warning, putting MATLAB in debug mode, paused at the line that generated the warning. The M-file must be in a directory that is on the search path or in the current directory. Use `dbcont` or `dbstep` to resume execution.

`dbstop if naninf` or `dbstop if infnan` stops execution when any M-file you subsequently run encounters an infinite value (`Inf`) or a value that is not a number (`NaN`), putting MATLAB in debug mode, paused at the line where `Inf` or `NaN` was encountered. For convenience, you can use either `naninf` or `infnan`—they perform in exactly the same manner. The M-file must be in a directory that is on the search path or in the current directory. Use `dbcont` or `dbstep` to resume execution. Use `dbquit` to exit from the Debugger.

Remarks

The `at`, `in`, and `if` keywords, familiar to users of the UNIX debugger dbx, are optional.

Examples

The file buggy, used in these examples, consists of three lines.

```
function z = buggy(x)
n = length(x);
z = (1:n)./x;
```

Stop at First Executable Line

The statements

```
dbstop in buggy
buggy(2:5)
```

stop execution at the first executable line in buggy

```
n = length(x);
```

The function

```
dbstep
```

advances to the next line, at which point you can examine the value of n.

Stop if Error

Because buggy only works on vectors, it produces an error if the input x is a full matrix. The statements

```
dbstop if error
buggy(magic(3))
```

produce

```
??? Error using ==> ./
Matrix dimensions must agree.
Error in ==> c:\buggy.m
On line 3 ==> z = (1:n)./x;
K»
```

and put MATLAB in debug mode.

Stop if InfNaN

In buggy, if any of the elements of the input x is zero, a division by zero occurs. The statements

```
dbstop if naninf
buggy(0:2)
```

produce

```
Warning: Divide by zero.
> In c:\buggy.m at line 3
K»
```

and put MATLAB in debug mode.

See Also

break, dbclear, dbcont, dbdown, dbquit, dbstack, dbstatus, dbstep, dbtype, dbup, keyboard, partialpath, return

Purpose List M-file with line numbers

Graphical Interface As an alternative to the `dbtype` function, you can see an M-file with line numbers by opening it in the Editor/Debugger.

Syntax

```
dbtype function
dbtype function start:end
```

Description `dbtype function` displays the contents of the specified M-file function with line numbers preceding each line. `function` must be the name of an M-file function or a `MATLABPATH` relative partial pathname.

`dbtype function start:end` displays the portion of the file specified by a range of line numbers.

You cannot use `dbtype` for built-in functions.

Examples To see only the input and output arguments for a function, that is, the first line of the M-file, type

```
dtype function 1
```

For example,

```
dbtype fileparts 1
```

returns

```
1    function [path, fname, extension,version] = fileparts(name)
```

See Also `dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbup`, `partialpath`

dbup

Purpose Change local workspace context

Graphical Interface As an alternative to the `dbup` function, you can select a different workspace from the **Stack** field in the toolbar of the Editor/Debugger.

Syntax

```
dbup
```

Description This function allows you to examine the calling M-file by using any other MATLAB function. In this way, you determine what led to the arguments' being passed to the called function.

`dbup` changes the current workspace context (at a breakpoint) to the workspace of the calling M-file.

Multiple `dbup` functions change the workspace context to each previous calling M-file on the stack until the base workspace context is reached. (It is not necessary, however, to move back to the current breakpoint to continue execution or to step to the next line.)

See Also `dbclear`, `dbcont`, `dbdown`, `dbquit`, `dbstack`, `dbstatus`, `dbstep`, `dbstop`, `dbtype`

Purpose Solve delay differential equations (DDEs) with constant delays

Syntax

```
sol = dde23(ddefun,lags,history,tspan)
sol = dde23(ddefun,lags,history,tspan,options)
sol = dde23(ddefun,lags,history,tspan,options,p1,p2,...)
```

Arguments

`ddefun` Function that evaluates the right side of the differential equations $y'(t) = f(t, y(t), y(t-\tau_1), \ldots, y(t-\tau_k))$. The function must have the form

```
dydt = ddefun(t,y,Z)
```

where `t` corresponds to the current t, `y` is a column vector that approximates $y(t)$, and `Z(:,j)` approximates $y(t-\tau_j)$ for delay τ_j = `lags(j)`. The output is a column vector corresponding to $f(t, y(t), y(t-\tau_1), \ldots, y(t-\tau_k))$.

`lags` Vector of constant, positive delays $\tau_1, \ldots, \tau_k$.

`history` Specify `history` in one of three ways:

- A function of t such that `y = history(t)` returns the solution $y(t)$ for $t \le t0$ as a column vector
- A constant column vector, if $y(t)$ is constant
- The solution `sol` from a previous integration, if this call continues that integration

`tspan` Interval of integration as a vector `[t0,tf]` with `t0 < tf`.

`options` Optional integration argument. A structure you create using the `ddeset` function. See `ddeset` for details.

`p1,p2,...` Optional parameters that `dde23` passes to `ddefun`, `history` if it is a function, and any functions you specify in `options`.

Description

`sol = dde23(ddefun,lags,history,tspan)` integrates the system of DDEs

$$y'(t) = f(t, y(t), y(t-\tau_1), \ldots, y(t-\tau_k))$$

on the interval $[t_0, t_f]$, where $\tau_1, \ldots, \tau_k$ are constant, positive delays and $t_0 < t_f$.

`dde23` returns the solution as a structure `sol`. Use the auxiliary function `deval` and the output `sol` to evaluate the solution at specific points `tint` in the interval `tspan = [t0,tf]`.

```
yint = deval(sol,tint)
```

The structure `sol` returned by `dde23` has the following fields.

`sol.x`	Mesh selected by `dde23`
`sol.y`	Approximation to $y(x)$ at the mesh points in `sol.x`.
`sol.yp`	Approximation to $y'(x)$ at the mesh points in `sol.x`
`sol.solver`	Solver name, `'dde23'`

`sol = dde23(ddefun,lags,history,tspan,options)` solves as above with default integration properties replaced by values in `options`, an argument created with `ddeset`. See `ddeset` and "Initial Value Problems for DDEs" in the MATLAB documentation for details.

Commonly used options are scalar relative error tolerance `'RelTol'` (`1e-3` by default) and vector of absolute error tolerances `'AbsTol'` (all components are `1e-6` by default).

Use the `'Jumps'` option to solve problems with discontinuities in the history or solution. Set this option to a vector that contains the locations of discontinuities in the solution prior to `t0` (the history) or in coefficients of the equations at known values of t after `t0`.

Use the `'Events'` option to specify a function that `dde23` calls to find where functions $g(t, y(t), y(t-\tau_1), \ldots, y(t-\tau_k))$ vanish. This function must be of the form

```
[value,isterminal,direction] = events(t,y,Z)
```

and contain an event function for each event to be tested. For the `k`th event function in `events`:

- `value(k)` is the value of the `k`th event function.
- `isterminal(k) = 1` if you want the integration to terminate at a zero of this event function and `0` otherwise.

- `direction(k) = 0` if you want `dde23` to compute all zeros of this event function, `+1` if only zeros where the event function increases, and `-1` if only zeros where the event function decreases.

If you specify the `'Events'` option and events are detected, the output structure `sol` also includes fields:

`sol.xe`	Row vector of locations of all events, i.e., times when an event function vanished
`sol.ye`	Matrix whose columns are the solution values corresponding to times in `sol.xe`
`sol.ie`	Vector containing indices that specify which event occurred at the corresponding time in `sol.xe`

`sol = dde23(ddefun,lags,history,tspan,options,p1,p2,...)` passes the parameters `p1,p2,...` to the DDE function as `ddefun(t,y,z,p1,p2,...)`, to the `history` function, if there is one, as `history (t,p1,p2,...)`, and similarly to all functions specified in `options`. Use `options = []` as a place holder if no options are set.

Examples

This example solves a DDE on the interval [0, 5] with lags 1 and 0.2. The function `ddex1de` computes the delay differential equations, and `ddex1hist` computes the history for `t <= 0`.

Note The demo `ddex1` contains the complete code for this example. To see the code in an editor, click the example name, or type `edit ddex1` at the command line. To run the example type `ddex1` at the command line.

```
sol = dde23(@ddex1de,[1, 0.2],@ddex1hist,[0, 5]);
```

This code evaluates the solution at 100 equally spaced points in the interval `[0,5]`, then plots the result.

```
tint = linspace(0,5);
yint = deval(sol,tint);
plot(tint,yint);
```

ddex1 shows how you can code this problem using subfunctions. For more examples see ddex2.

Algorithm

dde23 tracks discontinuities and integrates with the explicit Runge-Kutta (2,3) pair and interpolant of ode23. It uses iteration to take steps longer than the lags.

See Also

ddeget, ddeset, deval, @ (function_handle)

References

L.F. Shampine and S. Thompson, "Solving DDEs in MATLAB," *Applied Numerical Mathematics*, Vol. 37, 2001, pp. 441-458.

Purpose Set up advisory link

Syntax

```
rc = ddeadv(channel,'item','callback')
rc = ddeadv(channel,'item','callback','upmtx')
rc = ddeadv(channel,'item','callback','upmtx',format)
rc = ddeadv(channel,'item','callback','upmtx',format,timeout)
```

Description

`ddeadv` sets up an advisory link between MATLAB and a server application. When the data identified by the `item` argument changes, the string specified by the `callback` argument is passed to the `eval` function and evaluated. If the advisory link is a hot link, DDE modifies `upmtx`, the update matrix, to reflect the data in `item`.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

If successful, `ddeadv` returns 1 in variable, `rc`. Otherwise it returns 0.

Arguments

`channel`	Conversation channel from `ddeinit`.
`item`	String specifying the DDE item name for the advisory link. Changing the data identified by `item` at the server triggers the advisory link.
`callback`	String specifying the callback that is evaluated on update notification. Changing the data identified by `item` at the server causes `callback` to get passed to the `eval` function to be evaluated.
`upmtx` (*optional*)	String specifying the name of a matrix that holds data sent with an update notification. If `upmtx` is included, changing `item` at the server causes `upmtx` to be updated with the revised data. Specifying `upmtx` creates a hot link. Omitting `upmtx` or specifying it as an empty string creates a warm link. If `upmtx` exists in the workspace, its contents are overwritten. If `upmtx` does not exist, it is created.

`format` (*optional*)	Two-element array specifying the format of the data to be sent on update. The first element specifies the Windows clipboard format to use for the data. The only currently supported format is `cf_text`, which corresponds to a value of 1. The second element specifies the type of the resultant matrix. Valid types are `numeric` (the default, which corresponds to a value of `0`) and `string` (which corresponds to a value of `1`). The default format array is `[1 0]`.
`timeout` (*optional*)	Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). If advisory link is not established within `timeout` milliseconds, the function fails. The default value of `timeout` is three seconds.

Examples

Set up a hot link between a range of cells in Excel (Row 1, Column 1 through Row 5, Column 5) and the matrix `x`. If successful, display the matrix:

```
rc = ddeadv(channel, 'r1c1:r5c5', 'disp(x)', 'x');
```

Communication with Excel must have been established previously with a `ddeinit` command.

See Also

`ddeexec`, `ddeinit`, `ddepoke`, `ddereq`, `ddeterm`, `ddeunadv`

Purpose

Send string for execution

Syntax

```
rc = ddeexec(channel,'command')
rc = ddeexec(channel,'command','item')
rc = ddeexec(channel,'command','item',timeout)
```

Description

`ddeexec` sends a string for execution to another application via an established DDE conversation. Specify the string as the `command` argument.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

If successful, `ddeexec` returns 1 in variable, `rc`. Otherwise it returns 0.

Arguments

`channel`	Conversation channel from `ddeinit`.
`command`	String specifying the command to be executed.
`item` (*optional*)	String specifying the DDE item name for execution. This argument is not used for many applications. If your application requires this argument, it provides additional information for `command`. Consult your server documentation for more information.
`timeout` (*optional*)	Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). The default value of `timeout` is three seconds.

Examples

Given the channel assigned to a conversation, send a command to Excel:

```
rc = ddeexec(channel,'[formula.goto("r1c1")]')
```

Communication with Excel must have been established previously with a `ddeinit` command.

See Also

`ddeadv`, `ddeinit`, `ddepoke`, `ddereq`, `ddeterm`, `ddeunadv`

ddeget

Purpose Extract properties from options structure created with `ddeset`

Syntax

```
val = ddeget(options,'name')
val = ddeget(options,'name',default)
```

Description

`val = ddeget(options,'name')` extracts the value of the named property from the structure `options`, returning an empty matrix if the property value is not specified in `options`. It is sufficient to type only the leading characters that uniquely identify the property. Case is ignored for property names. `[]` is a valid `options` argument.

`val = ddeget(options,'name',default)` extracts the named property as above, but returns `val = default` if the named property is not specified in `options`. For example,

```
val = ddeget(opts,'RelTol',1e-4);
```

returns `val = 1e-4` if the `RelTol` is not specified in `opts`.

See Also `dde23`, `ddeset`

Purpose Initiate DDE conversation

Syntax

```
channel = ddeinit('service','topic')
```

Description `channel = ddeinit('service','topic')` returns a channel handle assigned to the conversation, which is used with other MATLAB DDE functions. `'service'` is a string specifying the service or application name for the conversation. `'topic'` is a string specifying the topic for the conversation.

Examples To initiate a conversation with Excel for the spreadsheet `'stocks.xls'`:

```
channel = ddeinit('excel','stocks.xls')

channel =
        0.00
```

See Also `ddeadv`, `ddeexec`, `ddepoke`, `ddereq`, `ddeterm`, `ddeunadv`

ddepoke

Purpose Send data to application

Syntax

```
rc = ddepoke(channel,'item',data)
rc = ddepoke(channel,'item',data,format)
rc = ddepoke(channel,'item',data,format,timeout)
```

Description

`ddepoke` sends data to an application via an established DDE conversation. `ddepoke` formats the data matrix as follows before sending it to the server application:

- String matrices are converted, element by element, to characters and the resulting character buffer is sent.
- Numeric matrices are sent as tab-delimited columns and carriage-return, line-feed delimited rows of numbers. Only the real part of nonsparse matrices are sent.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

If successful, `ddepoke` returns 1 in variable, `rc`. Otherwise it returns 0.

Arguments

`channel`	Conversation channel from `ddeinit`.
`item`	String specifying the DDE item for the data sent. Item is the server data entity that is to contain the data sent in the `data` argument.
`data`	Matrix containing the data to send.
`format` (*optional*)	Scalar specifying the format of the data requested. The value indicates the Windows clipboard format to use for the data transfer. The only format currently supported is `cf_text`, which corresponds to a value of `1`.
`timeout` (*optional*)	Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). The default value of `timeout` is three seconds.

Examples

Assume that a conversation channel with Excel has previously been established with `ddeinit`. To send a 5-by-5 identity matrix to Excel, placing the data in Row 1, Column 1 through Row 5, Column 5:

```
rc = ddepoke(channel, 'r1c1:r5c5', eye(5));
```

See Also

`ddeadv`, `ddeexec`, `ddeinit`, `ddereq`, `ddeterm`, `ddeunadv`

ddereq

Purpose Request data from application

Syntax

```
data = ddereq(channel,'item')
data = ddereq(channel,'item',format)
data = ddereq(channel,'item',format,timeout)
```

Description `ddereq` requests data from a server application via an established DDE conversation. `ddereq` returns a matrix containing the requested data or an empty matrix if the function is unsuccessful.

If you omit optional arguments that are not at the end of the argument list, you must substitute the empty matrix for the missing argument(s).

If successful, `ddereq` returns a matrix containing the requested data in variable, `data`. Otherwise, it returns an empty matrix.

Arguments

`channel`	Conversation channel from `ddeinit`.
`item`	String specifying the server application's DDE item name for the data requested.
`format` (*optional*)	Two-element array specifying the format of the data requested. The first element specifies the Windows clipboard format to use. The only currently supported format is `cf_text`, which corresponds to a value of 1. The second element specifies the type of the resultant matrix. Valid types are `numeric` (the default, which corresponds to `0`) and `string` (which corresponds to a value of `1`). The default format array is `[1 0]`.
`timeout` (*optional*)	Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). The default value of `timeout` is three seconds.

Examples Assume that we have an Excel spreadsheet `stocks.xls`. This spreadsheet contains the prices of three stocks in row 3 (columns 1 through 3) and the number of shares of these stocks in rows 6 through 8 (column 2). Initiate conversation with Excel with the command:

```
channel = ddeinit('excel','stocks.xls')
```

DDE functions require the *rxcy* reference style for Excel worksheets. In Excel terminology the prices are in `r3c1:r3c3` and the shares in `r6c2:r8c2`.

To request the prices from Excel:

```
prices = ddereq(channel,'r3c1:r3c3')

prices =
          42.50        15.00        78.88
```

To request the number of shares of each stock:

```
shares = ddereq(channel, 'r6c2:r8c2')

shares =
         100.00
         500.00
         300.00
```

See Also

`ddeadv`, `ddeexec`, `ddeinit`, `ddepoke`, `ddeterm`, `ddeunadv`

Purpose

Create/alter delay differential equations (DDE) options structure

Syntax

```
options = ddeset('name1',value1,'name2',value2,...)
options = ddeset(oldopts,'name1',value1,...)
options = ddeset(oldopts,newopts)
ddeset
```

Description

`options = ddeset('name1',value1,'name2',value2,...)` creates an integrator options structure `options` in which the named properties have the specified values. Any unspecified properties have default values. It is sufficient to type only the leading characters that uniquely identify the property. Case is ignored for property names.

`options = ddeset(oldopts,'name1',value1,...)` alters an existing options structure `oldopts`.

`options = ddeset(oldopts,newopts)` combines an existing options structure `oldopts` with a new options structure `newopts`. Any new properties overwrite corresponding old properties.

`ddeset` with no input arguments displays all property names and their possible values.

DDE Properties

These properties are available:

Property	Value	Description
`RelTol`	Positive scalar {`1e-3`}	Relative error tolerance that applies to all components of the solution vector. The estimated error in each integration step satisfies `|e(i)| <= max(RelTol*abs(y(i)),AbsTol(i))`.
`AbsTol`	Positive scalar or vector {`1e-6`}	Absolute error tolerance that applies to all components of the solution vector. Elements of a vector of tolerances apply to corresponding components of the solution vector.

Property	Value	Description
NormControl	on | {off}	Control error relative to norm of solution. Set this property on to request that dde23 control the error in each integration step with norm(e) <= max(RelTol*norm(y),AbsTol). By default dde23 uses a more stringent component-wise error control.
Stats	on | {off}	Display computational cost statistics.
Events	Function	The solver uses the specified function to locate where functions of t, y, Z vanish. See dde23 for details.
MaxStep	Positive scalar {0.1*tspan}	Upper bound on the magnitude of the step size. The default is one-tenth of the tspan interval.
InitialStep	Positive scalar	Suggested initial step size. The solver tries this first. By default the solver determines an initial step size automatically.
OutputFcn	Function	Installable output function. This output function is called by the solver after each time step. When a solver is called with no output arguments, OutputFcn defaults to the function odeplot. Otherwise, OutputFcn defaults to []. To create or modify an output function, see ODE Solver Output Properties in the "Differential Equations" section of the MATLAB documentation.
OutputSel	Vector of integers	Output selection indices. Specifies the components of the solution vector that dde23 passes to the OutputFcn. The default is all components.

Property	Value	Description
Jumps	Vector	Location of discontinuities in solution. Points t where the history or solution may have a jump discontinuity in a low-order derivative. See dde23 for details.
InitialY	Vector	Initial value of solution. By default the initial value of the solution is the value returned by history at the initial point. A different initial value can be supplied as the value of the InitialY property.

See Also

dde23, ddeget, @ (function_handle)

Purpose Terminate DDE conversation

Syntax

```
rc = ddeterm(channel)
```

Description `rc = ddeterm(channel)` accepts a channel handle returned by a previous call to `ddeinit` that established the DDE conversation. `ddeterm` terminates this conversation. `rc` is a return code where `0` indicates failure and `1` indicates success.

Examples To close a conversation channel previously opened with `ddeinit`:

```
rc = ddeterm(channel)

rc =

    1.00
```

See Also `ddeadv`, `ddeexec`, `ddeinit`, `ddepoke`, `ddereq`, `ddeunadv`

ddeunadv

Purpose Release advisory link

Syntax

```
rc = ddeunadv(channel,'item')
rc = ddeunadv(channel,'item',format)
rc = ddeunadv(channel,'item',format,timeout)
```

Description `ddeunadv` releases the advisory link between MATLAB and the server application established by an earlier `ddeadv` call. The `channel`, *`item`*, and `format` must be the same as those specified in the call to `ddeadv` that initiated the link. If you include the `timeout` argument but accept the default `format`, you must specify `format` as an empty matrix.

If successful, `ddeunadv` returns 1 in variable, `rc`. Otherwise it returns 0.

Arguments

`channel`	Conversation channel from `ddeinit`.
`item`	String specifying the DDE item name for the advisory link. Changing the data identified by `item` at the server triggers the advisory link.
`format` (*optional*)	Two-element array. This must be the same as the `format` argument for the corresponding `ddeadv` call.
`timeout` (*optional*)	Scalar specifying the time-out limit for this operation. `timeout` is specified in milliseconds. (1000 milliseconds = 1 second). The default value of `timeout` is three seconds.

Example To release an advisory link established previously with `ddeadv`:

```
rc = ddeunadv(channel, 'r1c1:r5c5')
rc =

    1.00
```

See Also `ddeadv`, `ddeexec`, `ddeinit`, `ddepoke`, `ddereq`, `ddeterm`

Purpose Deal inputs to outputs

Syntax

```
[Y1,Y2,Y3,...] = deal(X)
[Y1,Y2,Y3,...] = deal(X1,X2,X3,...)
```

Description

`[Y1,Y2,Y3,...] = deal(X)` copies the single input to all the requested outputs. It is the same as `Y1 = X`, `Y2 = X`, `Y3 = X`, ...

`[Y1,Y2,Y3,...] = deal(X1,X2,X3,...)` is the same as `Y1 = X1`; `Y2 = X2`; `Y3 = X3`; ...

Remarks

`deal` is most useful when used with cell arrays and structures via comma separated list expansion. Here are some useful constructions:

`[S.field] = deal(X)` sets all the fields with the name `field` in the structure array `S` to the value `X`. If `S` doesn't exist, use `[S(1:m).field] = deal(X)`.

`[X{:}] = deal(A.field)` copies the values of the field with name `field` to the cell array `X`. If `X` doesn't exist, use `[X{1:m}] = deal(A.field)`.

`[Y1,Y2,Y3,...] = deal(X{:})` copies the contents of the cell array `X` to the separate variables `Y1,Y2,Y3,...`

`[Y1,Y2,Y3,...] = deal(S.field)` copies the contents of the fields with the name `field` to separate variables `Y1,Y2,Y3,...`

Examples

Use `deal` to copy the contents of a 4-element cell array into four separate output variables.

```
C = {rand(3) ones(3,1) eye(3) zeros(3,1)};
[a,b,c,d] = deal(C{:})

a =

    0.9501    0.4860    0.4565
    0.2311    0.8913    0.0185
    0.6068    0.7621    0.8214

b =
```

```
     1
     1
     1

c =

     1     0     0
     0     1     0
     0     0     1

d =

     0
     0
     0
```

Use `deal` to obtain the contents of all the `name` fields in a structure array:

```
A.name = 'Pat'; A.number = 176554;
A(2).name = 'Tony'; A(2).number = 901325;
[name1,name2] = deal(A(:).name)

name1 =

Pat

name2 =

Tony
```

Purpose Strip trailing blanks from the end of a string

Syntax

```
str = deblank(str)
c = deblank(c)
```

Description `str = deblank(str)` removes the trailing blanks from the end of a character string *str*.

`c = deblank(c)`, when `c` is a cell array of strings, applies `deblank` to each element of `c`.

The `deblank` function is useful for cleaning up the rows of a character array.

Examples

```
A{1,1} = 'MATLAB    ';
A{1,2} = 'SIMULINK    ';
A{2,1} = 'Toolboxes    ';
A{2,2} = 'The MathWorks    ';

A =

    'MATLAB    '       'SIMULINK    '
    'Toolboxes    '    'The MathWorks    '


deblank(A)

ans =

    'MATLAB'        'SIMULINK'
    'Toolboxes'    'The MathWorks'
```

dec2base

Purpose Decimal number to base conversion

Syntax

```
str = dec2base(d,base)
str = dec2base(d,base,n)
```

Description `str = dec2base(d,base)` converts the nonnegative integer `d` to the specified `base.d` must be a nonnegative integer smaller than 2^52, and `base` must be an integer between 2 and 36. The returned argument `str` is a string.

`str = dec2base(d,base,n)` produces a representation with at least `n` digits.

Examples The expression `dec2base(23,2)` converts 23_{10} to base 2, returning the string `'10111'`.

See Also `base2dec`

Purpose Decimal to binary number conversion

Syntax

```
str = dec2bin(d)
str = dec2bin(d,n)
```

Description `str = dec2bin(d)` returns the binary representation of `d` as a string. `d` must be a nonnegative integer smaller than 2^52.

`str = dec2bin(d,n)` produces a binary representation with at least `n` bits.

Examples

```
ans =
    10111
```

See Also `bin2dec`, `dec2hex`

Purpose Decimal to hexadecimal number conversion

Syntax

```
str = dec2hex(d)
str = dec2hex(d,n)
```

Description `str = dec2hex(d)` converts the decimal integer `d` to its hexadecimal representation stored in a MATLAB string. `d` must be a nonnegative integer smaller than 2^52.

`str = dec2hex(d,n)` produces a hexadecimal representation with at least `n` digits.

Examples To convert decimal 1023 to hexadecimal,

```
dec2hex(1023)

ans =
    3FF
```

See Also `dec2bin`, `format`, `hex2dec`, `hex2num`

Purpose Deconvolution and polynomial division

Syntax

```
[q,r] = deconv(v,u)
```

Description `[q,r] = deconv(v,u)` deconvolves vector `u` out of vector `v`, using long division. The quotient is returned in vector `q` and the remainder in vector `r` such that `v = conv(u,q)+r`.

If `u` and `v` are vectors of polynomial coefficients, convolving them is equivalent to multiplying the two polynomials, and deconvolution is polynomial division. The result of dividing `v` by `u` is quotient `q` and remainder `r`.

Examples If

```
u = [1   2   3   4]
v = [10   20   30]
```

the convolution is

```
c = conv(u,v)
c =
    10     40     100     160     170     120
```

Use deconvolution to recover `u`:

```
[q,r] = deconv(c,u)
q =
    10    20    30
r =
    0      0      0      0      0      0
```

This gives a quotient equal to `v` and a zero remainder.

Algorithm `deconv` uses the `filter` primitive.

See Also `conv`, `residue`

del2

Purpose Discrete Laplacian

Syntax

```
L = del2(U)
L = del2(U,h)
L = del2(U,hx,hy)
L = del2(U,hx,hy,hz,...)
```

Definition

If the matrix `U` is regarded as a function $u(x, y)$ evaluated at the point on a square grid, then `4*del2(U)` is a finite difference approximation of Laplace's differential operator applied to u, that is:

$$l = \frac{\nabla^2 u}{4} = \frac{1}{4}\left(\frac{d^2 u}{dx^2} + \frac{d^2 u}{dy^2}\right)$$

where:

$$l_{ij} = \frac{1}{4}(u_{i+1,\ j} + u_{i-1,\ j} + u_{i,\ j+1} + u_{i,\ j-1}) - u_{i,}$$

in the interior. On the edges, the same formula is applied to a cubic extrapolation.

For functions of more variables $u(x, y, z, \ldots)$, `del2(U)` is an approximation,

$$l = \frac{\nabla^2 u}{2N} = \frac{1}{2N}\left(\frac{d^2 u}{dx^2} + \frac{d^2 u}{dy^2} + \frac{d^2 u}{dz^2} + \ldots\right)$$

where N is the number of variables in u.

Description

`L = del2(U)` where `U` is a rectangular array is a discrete approximation of

$$l = \frac{\nabla^2 u}{4} = \frac{1}{4}\left(\frac{d^2 u}{dx^2} + \frac{d^2 u}{dy^2}\right)$$

The matrix `L` is the same size as `U` with each element equal to the difference between an element of `U` and the average of its four neighbors.

-`L = del2(U)` when `U` is an multidimensional array, returns an approximation of

$$\frac{\nabla^2 u}{2N}$$

where N is `ndims(u)`.

`L = del2(U,h)` where `H` is a scalar uses `H` as the spacing between points in each direction (`h=1` by default).

`L = del2(U,hx,hy)` when `U` is a rectangular array, uses the spacing specified by `hx` and `hy`. If `hx` is a scalar, it gives the spacing between points in the x-direction. If `hx` is a vector, it must be of length `size(u,2)` and specifies the x-coordinates of the points. Similarly, if `hy` is a scalar, it gives the spacing between points in the y-direction. If `hy` is a vector, it must be of length `size(u,1)` and specifies the y-coordinates of the points.

`L = del2(U,hx,hy,hz,...)` where `U` is multidimensional uses the spacing given by `hx`, `hy`, `hz`, ...

Examples

The function

$$u(x, y) = x^2 + y^2$$

has

$$\nabla^2 u = 4$$

For this function, `4*del2(U)` is also `4`.

```
[x,y] = meshgrid(-4:4,-3:3);
U = x.*x+y.*y
U =
    25    18    13    10     9    10    13    18    25
    20    13     8     5     4     5     8    13    20
    17    10     5     2     1     2     5    10    17
    16     9     4     1     0     1     4     9    16
    17    10     5     2     1     2     5    10    17
    20    13     8     5     4     5     8    13    20
    25    18    13    10     9    10    13    18    25
```

```
V = 4*del2(U)
V =
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
     4     4     4     4     4     4     4     4     4
```

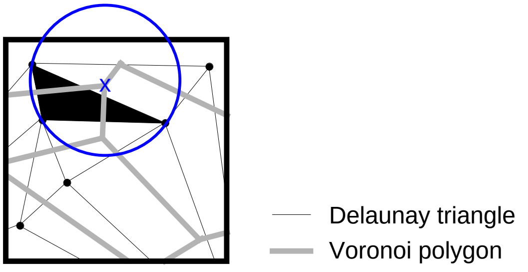
See Also `diff`, `gradient`

Purpose Delaunay triangulation

Syntax

```
TRI = delaunay(x,y)
```

Definition Given a set of data points, the *Delaunay triangulation* is a set of lines connecting each point to its natural neighbors. The Delaunay triangulation is related to the Voronoi diagram— the circle circumscribed about a Delaunay triangle has its center at the vertex of a Voronoi polygon.



Description `TRI = delaunay(x,y)` for the data points defined by vectors `x` and `y`, returns a set of triangles such that no data points are contained in any triangle's circumscribed circle. Each row of the `m`-by-3 matrix `TRI` defines one such triangle and contains indices into `x` and `y`. If the original data points are collinear or `x` is empty, the triangles cannot be computed and `delaunay` returns an empty matrix.

Remarks The Delaunay triangulation is used by: `griddata` (to interpolate scattered data), `voronoi` (to compute the `voronoi` diagram), and is useful by itself to create a triangular grid for scattered data points.

The functions `dsearch` and `tsearch` search the triangulation to find nearest neighbor points or enclosing triangles, respectively.

Visualization Use one of these functions to plot the output of `delaunay`:

`triplot`	Displays the triangles defined in the `m`-by-3 matrix `TRI`. See Example 1.
`trisurf`	Displays each triangle defined in the `m`-by-3 matrix `TRI` as a surface in 3-D space. To see a 2-D surface, you can supply a vector of some constant value for the third dimension. For example `trisurf(TRI,x,y,zeros(size(x)))` See Example 2.
`trimesh`	Displays each triangle defined in the `m`-by-3 matrix `TRI` as a mesh in 3-D space. To see a 2-D surface, you can supply a vector of some constant value for the third dimension. For example, `trimesh(TRI,x,y,zeros(size(x)))` produces almost the same result as `triplot`, except in 3-D space. See Example 2.

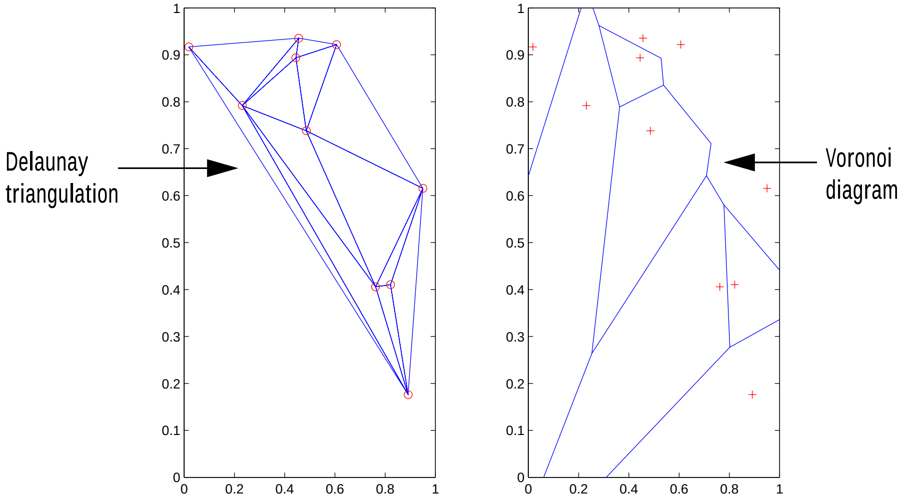
Examples

Example 1. Plot the Delaunay triangulation for 10 randomly generated points.

```
rand('state',0);
x = rand(1,10);
y = rand(1,10);
TRI = delaunay(x,y);
subplot(1,2,1),...
triplot(TRI,x,y)
axis([0 1 0 1]);
hold on;
plot(x,y,'or');
hold off
```

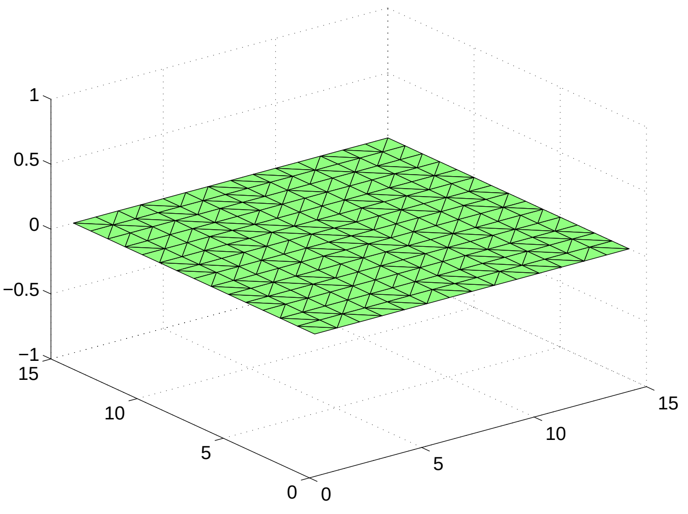
Compare the Voronoi diagram of the same points:

```
[vx, vy] = voronoi(x,y,TRI);
subplot(1,2,2),...
plot(x,y,'r+',vx,vy,'b-'),...
axis([0 1 0 1])
```



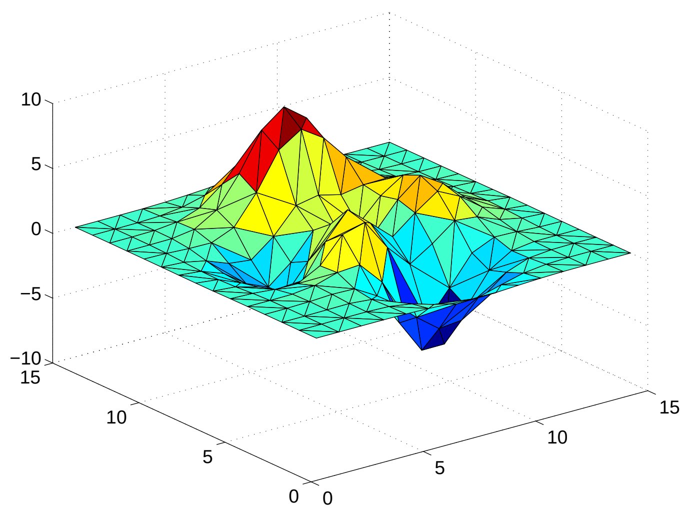
Example 2. Create a 2-D grid then use `trisurf` to plot its Delaunay triangulation in 3-D space by using `0`s for the third dimension.

```
[x,y] = meshgrid(1:15,1:15);
tri = delaunay(x,y);
trisurf(tri,x,y,zeros(size(x)))
```



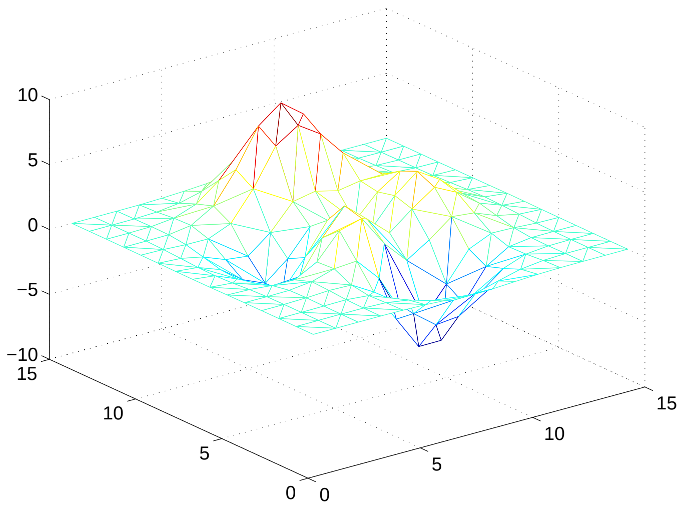
Next, generate peaks data as a 15-by-15 matrix, and use that data with the Delaunay triangulation to produce a surface in 3-D space.

```
z = peaks(15);
trisurf(tri,x,y,z)
```



You can use the same data with `trimesh` to produce a mesh in 3-D space.

```
trimesh(tri,x,y,z)
```



Algorithm

`delaunay` is based on Qhull . It uses the Qhull joggle option (`'QJ'`). For information about `qhull`, see `http://www.geom.umn.edu/software/qhull/`. For copyright information, see `http://www.geom.umn.edu/software/download/COPYING.html`.

See Also

`delaunay3`, `delaunayn`, `dsearch`, `griddata`, `plot`, `triplot`, `trimesh`, `trisurf`, `tsearch`, `voronoi`

References

[1] Barber, C. B., D.P. Dobkin, and H.T. Huhdanpaa, "The Quickhull Algorithm for Convex Hulls," *ACM Transactions on Mathematical Software*, Vol. 22, No. 4, Dec. 1996, p. 469-483. Available in HTML format at `http://www.acm.org/pubs/citations/journals/toms/1996-22-4/p469-barber/` and in PostScript format at `ftp://geom.umn.edu/pub/software/qhull-96.ps`.

[2] National Science and Technology Research Center for Computation and Visualization of Geometric Structures (The Geometry Center), University of Minnesota. 1993.

delaunay3

Purpose 3-D Delaunay tessellation

Syntax

```
TES = delaunay3(x,y,z)
```

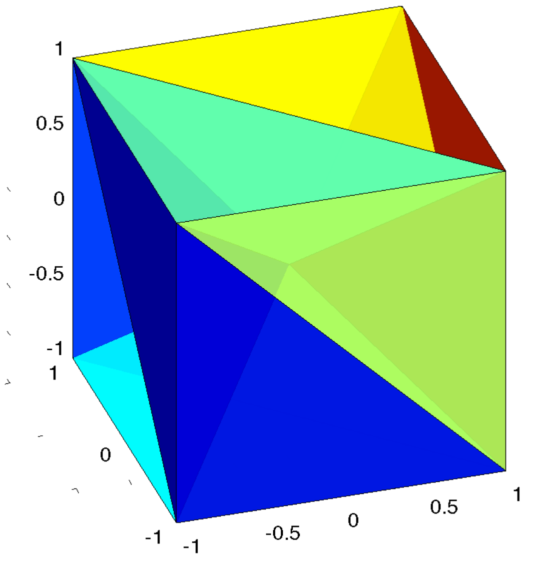
Description `TES = delaunay3(x,y,z)` returns an array `TES`, each row of which contains the indices of the points in `(x,y,z)` that make up a tetrahedron in the tessellation of `(x,y,z)`. `TES` is a `numtes`-by-`4` array where `numtes` is the number of facets in the tessellation. `x`, `y`, and `z` are vectors of equal length. If the original data points are collinear or `x`, `y`, and `z` define an insufficient number of points, the triangles cannot be computed and `delaunay3` returns an empty matrix.

Visualization Use `tetramesh` to plot `delaunay3` output. `tetramesh` displays the tetrahedrons defined in `TES` as mesh. `tetramesh` uses the default tranparency parameter value `'FaceAlpha' = 0.9`.

Example This example generates a 3-D Delaunay tessellation, then uses `tetramesh` to plot the tetrahedrons that form the corresponding simplex. `camorbit` rotates the camera position to provide a meaningful view of the figure.

```
d = [-1 1];
[x,y,z] = meshgrid(d,d,d);  % A cube
x = [x(:);0];
y = [y(:);0];
z = [z(:);0];
% [x,y,z] are corners of a cube plus the center.
Tes = delaunay3(x,y,z)

Tes =

     9    1    5    6
     3    9    1    5
     2    9    1    6
     2    3    9    4
     2    3    9    1
     7    9    5    6
     7    3    9    5
     8    7    9    6
     8    2    9    6
     8    2    9    4
```

```
     8     3     9     4
     8     7     3     9

X = [x(:) y(:) z(:)];
tetramesh(Tes,X);camorbit(20,0)
```



Algorithm `delaunay3` is based on Qhull [2]. It uses the Qhull joggle option (`'QJ'`). For information about `qhull`, see `http://www.geom.umn.edu/software/qhull/`. For copyright information, see `http://www.geom.umn.edu/software/download/COPYING.html`.

See Also `delaunay`, `delaunayn`

Reference

[1] Barber, C. B., D.P. Dobkin, and H.T. Huhdanpaa, "The Quickhull Algorithm for Convex Hulls," *ACM Transactions on Mathematical Software*, Vol. 22, No. 4, Dec. 1996, p. 469-483. Available in HTML format at `http://www.acm.org/pubs/citations/journals/toms/1996-22-4/p469-barber/` and in PostScript format at `ftp://geom.umn.edu/pub/software/qhull-96.ps`.

[2] National Science and Technology Research Center for Computation and Visualization of Geometric Structures (The Geometry Center), University of Minnesota. 1993.

Purpose n-D Delaunay tessellation

Syntax

```
T = delaunayn(X)
```

Description `T = delaunayn(X)` computes a set of simplices such that no data points of `X` are contained in any circumspheres of the simplices. The set of simplices forms the Delaunay tessellation. `X` is an `m`-by-`n` array representing `m` points in `n`-D space. `T` is a `numt`-by-(`n+1`) array where each row contains the indices into `X` of the vertices of the corresponding simplex.

Visualization Plotting the output of `delaunayn` depends of the value of `n`:

- For `n = 2`, use `triplot`, `trisurf`, or `trimesh` as you would for `delaunay`.
- For `n = 3`, use `tetramesh` as you would for `delaunay3`.

  For more control over the color of the facets, use `patch` to plot the output. For an example, see “Tessellation and Interpolation of Scattered Data in Higher Dimensions” in the MATLAB documentation.
- You cannot plot `delaunayn` output for `n > 3`.

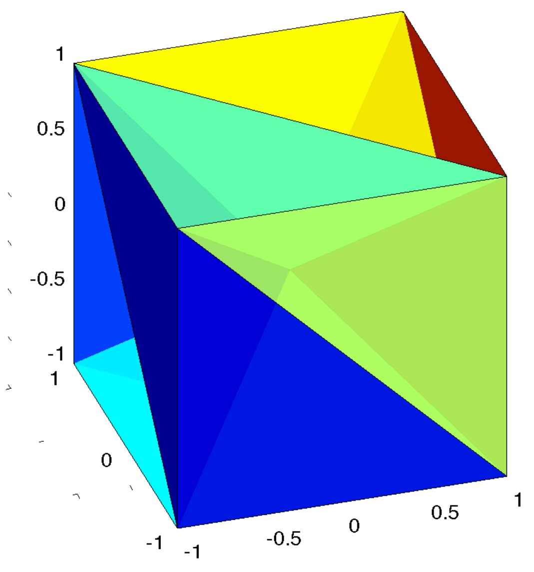
Example This example generates an n-D Delaunay tessellation, where `n = 3`.

```
d = [-1 1];
[x,y,z] = meshgrid(d,d,d);  % A cube
x = [x(:);0];
y = [y(:);0];
z = [z(:);0];
% [x,y,z] are corners of a cube plus the center.
X = [x(:) y(:) z(:)];
Tes = delaunayn(X)

Tes =
   9   1   5   6
   3   9   1   5
   2   9   1   6
   2   3   9   4
   2   3   9   1
   7   9   5   6
   7   3   9   5
   8   7   9   6
```

```
8    2    9    6
8    2    9    4
8    3    9    4
8    7    3    9
```

You can use `tetramesh` to visualize the tetrahedrons that form the corresponding simplex. `camorbit` rotates the camera position to provide a meaningful view of the figure.

```
tetramesh(Tes,X);camorbit(20,0)
```



Algorithm

`delaunayn` is based on Qhull [2],. It uses the Qhull joggle option (`'QJ'`). For information about `qhull`, see `http://www.geom.umn.edu/software/qhull/`. For copyright information, see `http://www.geom.umn.edu/software/download/COPYING.html`.

See Also

`convhulln`, `delaunayn`, `delaunay3`, `tetramesh`, `voronoin`

Reference

[1] Barber, C. B., D.P. Dobkin, and H.T. Huhdanpaa, "The Quickhull Algorithm for Convex Hulls," *ACM Transactions on Mathematical Software*, Vol. 22, No. 4, Dec. 1996, p. 469-483. Available in HTML format at

`http://www.acm.org/pubs/citations/journals/toms/1996-22-4/p469-barber/` and in PostScript format at `ftp://geom.umn.edu/pub/software/qhull-96.ps`.

[2] National Science and Technology Research Center for Computation and Visualization of Geometric Structures (The Geometry Center), University of Minnesota. 1993.

Purpose Delete files or graphics objects

Graphical Interface As an alternative to the `delete` function, you can delete files using the Current Directory browser.

Syntax

```
delete filename
delete(h)
delete('filename')
```

Description

`delete filename` deletes the named file from the disk. The `filename` may include an absolute pathname or a pathname relative to the current directory. The `filename` may also include wildcards, (*).

`delete(h)` deletes the graphics object with handle `h`. The function deletes the object without requesting verification even if the object is a window.

`delete('filename')` is the function form of `delete`. Use this form when the filename is stored in a string.

Note MATLAB does not ask for confirmation when you enter the `delete` command. To avoid accidentally losing files or graphics objects that you need, make sure that you have accurately specified the items you want deleted.

Examples

To delete all files with a `.mat` extension in the `../mytests/` directory, type

```
delete('../mytests/*.mat')
```

To delete a directory, use `rmdir` rather than `delete`:

```
rmdir mydirectory
```

See Also

`dir`, `edit`, `mkdir`, `rmdir`, `type`

delete (COM)

Purpose

Delete a COM control or server

Syntax

```
delete(h)
```

Arguments

`h`
Handle for a COM object previously returned from `actxcontrol`, `actxserver`, `get`, or `invoke`.

Description

Release all interfaces derived from the specified COM server or control, and then delete the server or control itself. This is different from releasing an interface, which releases and invalidates only that interface.

Examples

Create a Microsoft Calender application. Then create a `TitleFont` interface and use it to change the appearance of the font of the calendar's title:

```
f = figure('pos',[300 300 500 500]);
cal = actxcontrol('mscal.calendar', [0 0 500 500], f);

TFont = get(cal, 'TitleFont')
TFont =
   Interface.mscal.calendar.TitleFont

set(TFont, 'Name', 'Viva BoldExtraExtended');
set(TFont, 'Bold', 0);
```

When you're finished working with the title font, release the `TitleFont` interface:

```
release(TFont);
```

Now create a `GridFont` interface and use it to modify the size of the calendar's date numerals:

```
GFont = get(cal, 'GridFont')
GFont =
   Interface.mscal.calendar.GridFont

set(GFont, 'Size', 16);
```

When you're done, delete the `cal` object and the figure window. Deleting the `cal` object also releases all interfaces to the object (e.g., `GFont`):

```
delete(cal);
delete(f);
clear f;
```

Note that, although the object and interfaces themselves have been destroyed, the variables assigned to them still reside in the MATLAB workspace until you remove them with `clear`.

```
whos
  Name          Size                        Bytes  Class

  GFont         1x1                             0  handle
  TFone         1x1                             0  handle
  cal           1x1                             0  handle

Grand total is 3 elements using 0 bytes
```

See Also `release`, `save`, `load`, `actxcontrol`, `actxserver`

Purpose

Remove a serial port object from memory

Syntax

```
delete(obj)
```

Arguments

`obj`	A serial port object or an array of serial port objects.

Description

`delete(obj)` removes `obj` from memory.

Remarks

When you delete `obj`, it becomes an *invalid* object. Because you cannot connect an invalid serial port object to the device, you should remove it from the workspace with the `clear` command. If multiple references to `obj` exist in the workspace, then deleting one reference invalidates the remaining references.

If `obj` is connected to the device, it has a `Status` property value of `open`. If you issue `delete` while `obj` is connected, then the connection is automatically broken. You can also disconnect `obj` from the device with the `fclose` function.

If you use the `help` command to display help for `delete`, then you need to supply the pathname shown below.

```
help serial/delete
```

Example

This example creates the serial port object `s`, connects `s` to the device, writes and reads text data, disconnects `s` from the device, removes `s` from memory using `delete`, and then removes `s` from the workspace using `clear`.

```
s = serial('COM1');
fopen(s)
fprintf(s,'*IDN?')
idn = fscanf(s);
fclose(s)
delete(s)
clear s
```

See Also

Functions

`clear`, `fclose`, `isvalid`

Properties

`Status`

delete (timer)

Purpose Remove a timer object from memory

Syntax

```
delete(obj)
```

Description `delete(obj)` removes timer object, `obj`, from memory. If `obj` is an array of timer objects, `delete` removes all the objects from memory.

When you delete a timer object, it becomes invalid and cannot be reused. Use the `clear` command to remove invalid timer objects from the workspace.

If multiple references to a timer object exist in the workspace, deleting the timer object invalidates the remaining references. Use the `clear` command to remove the remaining references to the object from the workspace.

See Also `clear`, `isvalid`, `timer`

Purpose

Remove custom property from COM object

Syntax

```
deleteproperty(h, 'propertyname')
```

Arguments

`h`
Handle for a COM object previously returned from `actxcontrol`, `actxserver`, `get`, or `invoke`.

`propertyname`
A string specifying the name of the custom property to delete.

Description

Delete a property, `propertyname`, from the custom properties belonging to object or interface, `h`. You can only delete properties that have been created with `addproperty`.

Examples

Create an `mwsamp` control and add a new property named `Position` to it. Assign an array value to the property:

```
f = figure('pos', [100 200 200 200]);
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 200 200], f);
get(h)
     Label: 'Label'
    Radius: 20

addproperty(h, 'Position');
set(h, 'Position', [200 120]);
get(h)
       Label: 'Label'
      Radius: 20
    Position: [200 120]
```

Delete the custom `Position` property:

```
deleteproperty(h, 'Position');
get(h)
     Label: 'Label'
    Radius: 20
```

See Also

`addproperty`, `get`, `set`, `inspect`

demo

Purpose Access product demos via Help browser

Syntax

```
demo
demo subtopic
demo subtopic category
```

Description

`demo` opens the **Demos** panel in the Help browser. In the left pane, expand the listing for a product area (for example, MATLAB). Within that product area, expand the listing for a product or product category (for example, MATLAB Graphics). Select a specific demo from the list (for example, Visualizing Sound). In the right pane, view instructions for using the demo. For more information, see Running Demonstrations. For platforms that do not support Java GUIs, the demos are presented in a non-Java interface. To run a demo from the command line, type the demo name. For playshow demos, that is those demos in which the H1 line begins with two comment symbols (`%%`), type `playshow` followed by the demo name.

`demo` *`subtopic`* opens the **Demos** panel in the Help browser with the specified subtopic expanded. Subtopics are `matlab`, `toolbox`, `simulink`, and `blockset`.

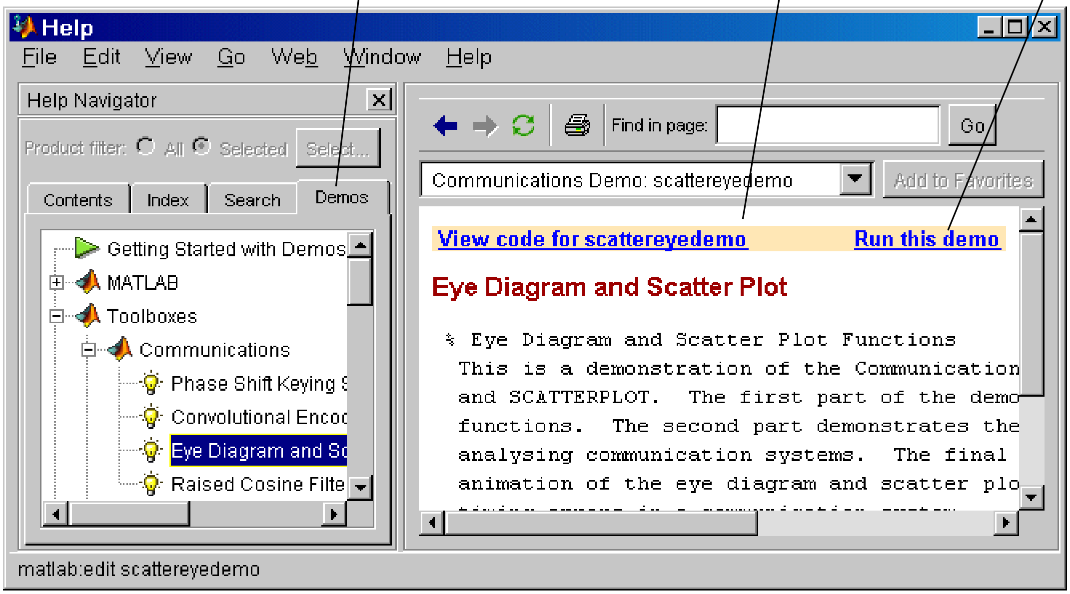
`demo` *`subtopic product`* opens the **Demos** panel in the Help browser to the specified product or category within the subtopic.

Type demo to access the **Demos** panel in the Help browser.

View the demos for products installed on your system. When you choose a demo, information about it appears in the display pane.

To run an M-file demo, click this link.

When you click this link, the M-file source code for the demo appears in your editor.



Examples

Accessing Toolbox Demos

To find the demos relating to the Communications Toolbox, type

```
demo toolbox communication
```

The Help browser opens to the **Demos** panel with the Toolbox subtopic expanded and with the Communications product highlighted and expanded to show the available demos.

Accessing the Simulink Automotive Demos

To accesses the automotive demos within Simulink, type

```
demo simulink automotive
```

The **Demos** panel opens with the Simulink subtopic and Automotive category expanded.

Running a Demo from the Command Line

Type

```
vibes
```

to run a visualization demonstration showing an animated L-shaped membrane.

Running a Playshow Demo from the Command Line

Type

```
quake
```

to run an earthquake data demo. Not much appears to happen. This is because `quake` is a playshow demo. Verify this by viewing the M-file, `quake.m`, for example, by typing

```
edit quake
```

The first line, that is, the H1 line for `quake` is

```
%% Loma Prieta Earthquake
```

The `%%` indicates that `quake` is a playshow demo. So to run it, type

```
playshow quake
```

and the earthquake demo runs.

See Also

`help`, `helpbrowser`, `helpwin`, `lookfor`

Purpose List the dependent directories of an M-file or P-file

Syntax

```
list = depdir('file_name');
[list,prob_files,prob_sym,prob_strings] = depdir('file_name');
[...] = depdir('file_name1','file_name2',...);
```

Description The `depdir` function lists the directories of all of the functions that a specified M-file or P-file needs to operate. This function is useful for finding all of the directories that need to be included with a runtime application and for determining the runtime path.

`list = depdir('file_name')` creates a cell array of strings containing the directories of all the M-files and P-files that `file_name.m` or `file_name.p` uses. This includes the second-level files that are called directly by `file_name`, as well as the third-level files that are called by the second-level files, and so on.

`[list,prob_files,prob_sym,prob_strings] = depdir('file_name')` creates three additional cell arrays containing information about any problems with the `depdir` search. `prob_files` contains filenames that `depdir` was unable to parse. `prob_sym` contains symbols that `depdir` was unable to find. `prob_strings` contains callback strings that `depdir` was unable to parse.

`[...] = depdir('file_name1','file_name2',...)` performs the same operation for multiple files. The dependent directories of all files are listed together in the output cell arrays.

Example

```
list = depdir('mesh')
```

See Also `depfun`

depfun

Purpose List the dependent functions of an M-file or P-file

Syntax

```
list = depfun('file_name');
[list,builtins,classes] = depfun('file_name');
[list,builtins,classes,prob_files,prob_sym,eval_strings,...
  called_from,java_classes] = depfun('file_name');
[...] = depfun('file_name1','file_name2',...);
[...] = depfun('fig_file_name');
[...] = depfun(...,'-toponly');
```

Description The `depfun` function lists all of the functions and scripts, as well as built-in functions, that a specified M-file needs to operate. This is useful for finding all of the M-files that you need to compile for a MATLAB runtime application.

`list = depfun('file_name')` creates a cell array of strings containing the paths of all the files that `file_name.m` uses. This includes the second-level files that are called directly by `file_name.m`, as well as the third-level files that are called by the second-level files, and so on.

Note If `depfun` reports that "`These files could not be parsed:`" or if the `prob_files` output below is nonempty, then the rest of the output of `depfun` might be incomplete. You should correct the problematic files and invoke `depfun` again.

`[list,builtins,classes] = depfun('file_name')` creates three cell arrays containing information about dependent functions. `list` contains the paths of all the files that `file_name` and its subordinates use. `builtins` contains the built-in functions that `file_name` and its subordinates use. `classes` contains the MATLAB classes that `file_name` and its subordinates use.

`[list,builtins,classes,prob_files,prob_sym,eval_strings,... called_from,java_classes] = depfun('file_name')` creates additional cell arrays or structure arrays containing information about any problems with the `depfun` search and about where the functions in `list` are invoked. The additional outputs are:

- `prob_files`, which indicates which files `depfun` was unable to parse, find, or access. Parsing problems can arise from MATLAB syntax errors. `prob_files` is a structure array whose fields are:
  - `name`, which gives the names of the files
  - `listindex`, which tells where the files appeared in `list`
  - `errmsg`, which describes the problems
- `prob_sym`, which indicates which symbols `depfun` was unable to resolve as functions or variables. It is a structure array whose fields are:
  - `fcn_id`, which tells where the files appeared in `list`
  - `name`, which gives the names of the problematic symbols
- `eval_strings`, which indicates usage of these evaluation functions: `eval`, `evalc`, `evalin`, `feval`. When preparing a runtime application, you should examine this output to determine whether an evaluation function invokes a function that does not appear in `list`. The output `eval_strings` is a structure array whose fields are:
  - `fcn_name`, which give the names of the files that use evaluation functions
  - `lineno`, which gives the line numbers in the files where the evaluation functions appear
- `called_from`, a cell array of the same length as `list`. This cell array is arranged so that

  `list(called_from{i})`

  returns all functions in `file_name` that invoke the function `list{i}`.
- `java_classes`, a cell array of Java class names that `file_name` and its subordinates use

`[...] = depfun('file_name1','file_name2',...)` performs the same operation for multiple files. The dependent functions of all files are listed together in the output arrays.

`[...] = depfun('fig_file_name')` looks for dependent functions among the callback strings of the GUI elements that are defined in the `.fig` or `.mat` file named `fig_file_name`.

`[...] = depfun(...,'-toponly')` differs from the other syntaxes of depfun in that it examines *only* the files listed explicitly as input arguments. It does not examine the files on which they depend. In this syntax, the flag `'-toponly'` must be the last input argument.

Notes

1. If `depfun` does not find a file called `hginfo.mat` on the path, then it creates one. This file contains information about Handle Graphics callbacks.
2. If your application uses toolbar items from the MATLAB default figure window, then you must include `'FigureToolBar.fig'` in your input to `depfun`.
3. If your application uses menu items from the MATLAB default figure window, then you must include `'FigureMenuBar.fig'` in your input to `depfun`.
4. Because many built-in Handle Graphics functions invoke `newplot`, the list produced by `depfun` always includes the functions on which `newplot` is dependent:
   - '*matlabroot*\toolbox\matlab\graphics\newplot.m'
   - '*matlabroot*\toolbox\matlab\graphics\closereq.m'
   - '*matlabroot*\toolbox\matlab\graphics\gcf.m'
   - '*matlabroot*\toolbox\matlab\graphics\gca.m'
   - '*matlabroot*\toolbox\matlab\graphics\private\clo.m'
   - '*matlabroot*\toolbox\matlab\general\@char\delete.m'
   - '*matlabroot*\toolbox\matlab\lang\nargchk.m'
   - '*matlabroot*\toolbox\matlab\uitools\allchild.m'
   - '*matlabroot*\toolbox\matlab\ops\setdiff.m'
   - '*matlabroot*\toolbox\matlab\ops\@cell\setdiff.m'
   - '*matlabroot*\toolbox\matlab\iofun\filesep.m'
   - '*matlabroot*\toolbox\matlab\ops\unique.m'
   - '*matlabroot*\toolbox\matlab\elmat\repmat.m'
   - '*matlabroot*\toolbox\matlab\datafun\sortrows.m'
   - '*matlabroot*\toolbox\matlab\strfun\deblank.m'
   - '*matlabroot*\toolbox\matlab\ops\@cell\unique.m'
   - '*matlabroot*\toolbox\matlab\strfun\@cell\deblank.m'
   - '*matlabroot*\toolbox\matlab\datafun\@cell\sort.m'
   - '*matlabroot*\toolbox\matlab\strfun\cellstr.m'
   - '*matlabroot*\toolbox\matlab\datatypes\iscell.m'
   - '*matlabroot*\toolbox\matlab\strfun\iscellstr.m'

- '*matlabroot*\toolbox\matlab\datatypes\cellfun.dll'

Examples

```
list = depfun('mesh'); % Files mesh.m depends on
list = depfun('mesh','-toponly') % Files mesh.m depends on
directly
[list,builtins,classes] = depfun('gca');
```

See Also

`depdir`, `profile`

det

Purpose Matrix determinant

Syntax

```
d = det(X)
```

Description `d = det(X)` returns the determinant of the square matrix `X`. If `X` contains only integer entries, the result `d` is also an integer.

Remarks Using `det(X) == 0` as a test for matrix singularity is appropriate only for matrices of modest order with small integer entries. Testing singularity using `abs(det(X)) <= tolerance` is not recommended as it is difficult to choose the correct tolerance. The function `cond(X)` can check for singular and nearly singular matrices.

Algorithm The determinant is computed from the triangular factors obtained by Gaussian elimination

```
[L,U] = lu(A)
s =  det(L)        % This is always +1 or -1
det(A) = s*prod(diag(U))
```

Examples The statement `A = [1   2   3;  4   5   6;  7   8   9]`

produces

```
A =
     1       2       3
     4       5       6
     7       8       9
```

This happens to be a singular matrix, so `d = det(A)` produces `d = 0`. Changing `A(3,3)` with `A(3,3) = 0` turns `A` into a nonsingular matrix. Now `d = det(A)` produces `d = 27`.

See Also `cond`, `condest`, `inv`, `lu`, `rref`

The arithmetic operators `\`, `/`

Purpose Remove linear trends.

Syntax

```
y = detrend(x)
y = detrend(x,'constant')
y = detrend(x,'linear',bp)
```

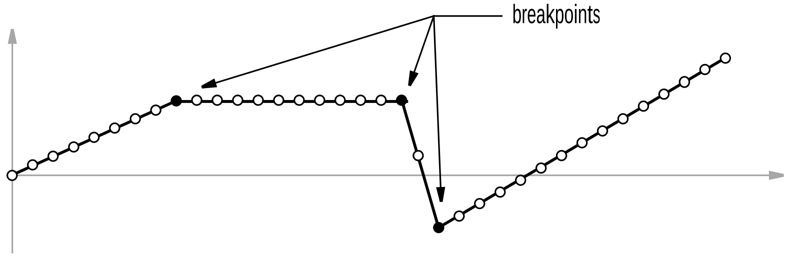
Description

detrend removes the mean value or linear trend from a vector or matrix, usually for FFT processing.

y = detrend(x) removes the best straight-line fit from vector x and returns it in y. If x is a matrix, detrend removes the trend from each column.

y = detrend(x,'constant') removes the mean value from vector x or, if x is a matrix, from each column of the matrix.

y = detrend(x,'linear',bp) removes a continuous, piecewise linear trend from vector x or, if x is a matrix, from each column of the matrix. Vector bp contains the indices of the breakpoints between adjacent linear segments. The breakpoint between two segments is defined as the data point that the two segments share.



detrend(x,'linear'), with no breakpoint vector specified, is the same as detrend(x).

Example

```
sig = [0 1 -2 1 0 1 -2 1 0];      % signal with no linear trend
trend = [0 1 2 3 4 3 2 1 0];      % two-segment linear trend
x = sig+trend;                    % signal with added trend
y = detrend(x,'linear',5)         % breakpoint at 5th element
```

```
y =

   -0.0000
    1.0000
   -2.0000
    1.0000
    0.0000
    1.0000
   -2.0000
    1.0000
   -0.0000
```

Note that the breakpoint is specified to be the fifth element, which is the data point shared by the two segments.

Algorithm

`detrend` computes the least-squares fit of a straight line (or composite line for piecewise linear trends) to the data and subtracts the resulting function from the data. To obtain the equation of the straight-line fit, use `polyfit`.

See Also

`polyfit`

Purpose

Evaluate the solution of a differential equation problem

Syntax

```
sxint = deval(sol,xint)
sxint = deval(xint,sol)
sxint = deval(sol,xint,idx)
sxint = deval(xint,sol,idx)
```

Description

`sxint = deval(sol,xint)` and `sxint = deval(xint,sol)` evaluate the solution of a differential equation problem. `sol` is a structure returned by one of these solvers:

- An initial value problem solver (`ode45`, `ode23`, `ode113`, `ode15s`, `ode23s`, `ode23t`, `ode23tb`),
- The delay differential equations solver (`dde23`),
- The boundary value problem solver (`bvp4c`).

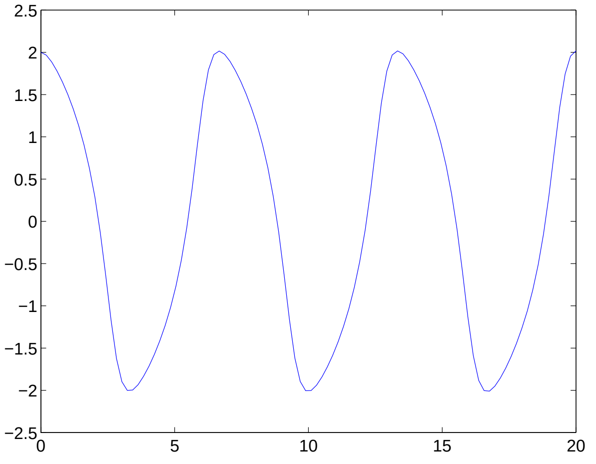
`xint` is a point or a vector of points at which you want the solution. The elements of `xint` must be in the interval `[sol.x(1),sol.x(end)]`. For each `i`, `sxint(:,i)` is the solution at `xint(i)`.

`sxint = deval(sol,xint,idx)` and `sxint = deval(xint,sol,idx)` evaluate as above but return only the solution components with indices listed in `idx`.

Example

This example solves the system $y' = \mathrm{vdp1}(t, y)$ using `ode45`, and evaluates and plots the first component of the solution at 100 points in the interval `[0,20]`.

```
sol = ode45(@vdp1,[0 20],[2 0]);
x = linspace(0,20,100);
y = deval(sol,x,1);
plot(x,y);
```



See Also

ODE solvers: `ode45`, `ode23`, `ode113`, `ode15s`, `ode23s`, `ode23t`, `ode23tb`

DDE solver: `dde23`

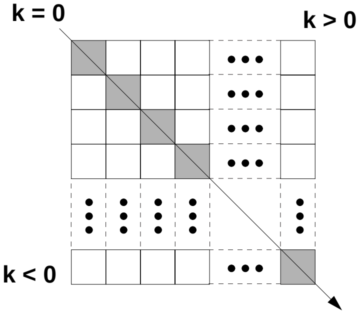
BVP solver: `bvp4c`

Purpose Diagonal matrices and diagonals of a matrix

Syntax

```
X = diag(v,k)
X = diag(v)
v = diag(X,k)
v = diag(X)
```

Description `X = diag(v,k)` when `v` is a vector of `n` components, returns a square matrix `X` of order `n+abs(k)`, with the elements of `v` on the `k`th diagonal. `k = 0` represents the main diagonal, `k > 0` above the main diagonal, and `k < 0` below the main diagonal.



`X = diag(v)` puts `v` on the main diagonal, same as above with `k = 0`.

`v = diag(X,k)` for matrix `X`, returns a column vector `v` formed from the elements of the `k`th diagonal of `X`.

`v = diag(X)` returns the main diagonal of `X`, same as above with `k = 0`.

Examples `diag(diag(X))` is a diagonal matrix.

`sum(diag(X))` is the trace of `X`.

The statement

```
diag(-m:m)+diag(ones(2*m,1),1)+diag(ones(2*m,1),-1)
```

produces a tridiagonal matrix of order `2*m+1`.

See Also `spdiags`, `tril`, `triu`

Purpose Create and display dialog box

Syntax

```
h = dialog('PropertyName',PropertyValue,...)
```

Description

`h = dialog('`*`PropertyName`*`',PropertyValue,...)` returns a handle to a dialog box. This function creates a figure graphics object and sets the figure properties recommended for dialog boxes. You can specify any valid figure property value.

See Also

`errordlg`, `figure`, `helpdlg`, `inputdlg`, `pagedlg`, `printdlg`, `questdlg`, `uiwait`, `uiresume`, `warndlg`

“Predefined Dialog Boxes” for related functions

diary

Purpose

Save session to a file

Syntax

```
diary
diary('filename')
diary off
diary on
diary filename
```

Description

The `diary` function creates a log of keyboard input and the resulting output (except it does not include graphics). The output of `diary` is an ASCII file, suitable for printing or for inclusion in reports and other documents. If you do not specify `filename`, MATLAB creates a file named `diary` in the current directory.

`diary` toggles `diary` mode on and off. To see the status of `diary`, type `get(0,'Diary')`. MATLAB returns either `on` or `off` indicating the `diary` status.

`diary('filename')` writes a copy of all subsequent keyboard input and the resulting output (except it does not include graphics) to the named file, where `filename` is the full pathname or `filename` is in the current MATLAB directory. If the file already exists, output is appended to the end of the file. You cannot use a `filename` called `off` or `on`. To see the name of the `diary` file, use `get(0,'DiaryFile')`.

`diary off` suspends the diary.

`diary on` resumes diary mode using the current filename, or the default filename `diary` if none has yet been specified.

`diary filename` is the unquoted form of the syntax.

See Also

Command History window in MATLAB Development Environment documentation

Purpose Differences and approximate derivatives

Syntax

```
Y = diff(X)
Y = diff(X,n)
Y = diff(X,n,dim)
```

Description `Y = diff(X)` calculates differences between adjacent elements of `X`.

If `X` is a vector, then `diff(X)` returns a vector, one element shorter than `X`, of differences between adjacent elements:

```
[X(2)-X(1) X(3)-X(2) ... X(n)-X(n-1)]
```

If `X` is a matrix, then `diff(X)` returns a matrix of row differences:

```
[X(2:m,:)-X(1:m-1,:)]
```

In general, `diff(X)` returns the differences calculated along the first non-singleton (`size(X,dim) > 1`) dimension of `X`.

`Y = diff(X,n)` applies `diff` recursively `n` times, resulting in the nth difference. Thus, `diff(X,2)` is the same as `diff(diff(X))`.

`Y = diff(X,n,dim)` is the nth difference function calculated along the dimension specified by scalar `dim`. If order `n` equals or exceeds the length of dimension `dim`, `diff` returns an empty array.

Remarks Since each iteration of `diff` reduces the length of `X` along dimension `dim`, it is possible to specify an order `n` sufficiently high to reduce `dim` to a singleton (`size(X,dim) = 1`) dimension. When this happens, `diff` continues calculating along the next nonsingleton dimension.

Examples The quantity `diff(y)./diff(x)` is an approximate derivative.

```
x = [1 2 3 4 5];
y = diff(x)
y =
     1     1     1     1

z = diff(x,2)
z =
```

```
     0     0     0
```

Given,

```
A = rand(1,3,2,4);
```

`diff(A)` is the first-order difference along dimension 2.

`diff(A,3,4)` is the third-order difference along dimension 4.

See Also `gradient`, `prod`, `sum`

Purpose Display directory listing

Graphical Interface As an alternative to the `dir` function, use the Current Directory browser.

Syntax

```
dir
dir name
files = dir('name')
```

Description `dir` lists the files in the current working directory.

`dir name` lists the specified files. The `name` argument can be a pathname, filename, or can include both. You can use absolute and relative pathnames and wildcards (*).

`files = dir('directory')` returns the list of files in the specified directory (or the current directory, if `dirname` is not specified) to an `m`-by-`1` structure with the fields

`name`	Filename
`date`	Modification date
`bytes`	Number of bytes allocated to the file
`isdir`	`1` if name is a directory; `0` if not

Examples

List Directory Contents

To view the contents of the `matlab/audio` directory, type

```
dir $matlabroot/toolbox/matlab/audio
```

Using Wildcard and File Extension

To view the MAT files in your current working directory that include the term `java`, type

```
dir *java*.mat
```

MATLAB returns

```
java_array.mat  javafrmobj.mat  testjava.mat
```

Using Relative Pathname

To view the M-files in the MATLAB audio directory, type

```
dir(fullfile(matlabroot,'toolbox/matlab/audio/*.m'))
```

MATLAB returns

```
Contents.m          auread.m          soundsc.m
audiodevinfo.m      auwrite.m         wavplay.m
audioplayer.m       lin2mu.m          wavread.m
audioplayerreg.m    mu2lin.m          wavrecord.m
audiorecorder.m     prefspanel.m      wavwrite.m
audiouniquename.m   sound.m
```

Returning File List to Structure

To return the list of files to the variable `audio_files`, type

```
audio_files=dir(fullfile(matlabroot,'toolbox/matlab/audio/*.m')
)
```

MATLAB returns the information in a structure array.

```
audio_files =
19x1 struct array with fields:
    name
    date
    bytes
    isdir
```

Index into the structure to access a particular item. For example,

```
audio_files(3).name
ans =
audioplayer.m
```

See Also

`cd`, `copyfile`, `delete`, `fileattrib`, `filebrowser`, `ls`, `mkdir`, `movefile`, `rmdir`, `type`, `what`

Purpose Display text or array

Syntax

```
disp(X)
```

Description `disp(X)` displays an array, without printing the array name. If `X` contains a text string, the string is displayed.

Another way to display an array on the screen is to type its name, but this prints a leading "`X =`," which is not always desirable.

Note that `disp` does not display empty arrays.

Examples One use of `disp` in an M-file is to display a matrix with column labels:

```
disp('          Corn          Oats          Hay')
disp(rand(5,3))
```

which results in

```
          Corn          Oats          Hay
         0.2113        0.8474        0.2749
         0.0820        0.4524        0.8807
         0.7599        0.8075        0.6538
         0.0087        0.4832        0.4899
         0.8096        0.6135        0.7741
```

See Also `format`, `int2str`, `num2str`, `rats`, `sprintf`

disp (serial)

Purpose

Display serial port object summary information

Syntax

```
obj
disp(obj)
```

Arguments

`obj`	A serial port object or an array of serial port objects.

Description

`obj` or `disp(obj)` displays summary information for `obj`.

Remarks

In addition to the syntax shown above, you can display summary information for `obj` by excluding the semicolon when:

- Creating a serial port object
- Configuring property values using the dot notation

Use the display summary to quickly view the communication settings, communication state information, and information associated with read and write operations.

Example

The following commands display summary information for the serial port object `s`.

```
s = serial('COM1')
s.BaudRate = 300
s
```

Purpose Display information about timer object

Syntax

```
obj
disp(obj)
```

Description `obj` or `disp(obj)` displays summary information for timer object, `obj`.

If `obj` is an array of timer objects, `disp` outputs a table of summary information about the timer objects in the array.

In addition to the syntax shown above, you can display summary information for `obj` by excluding the semicolon when:

- Creating a timer object, using the `timer` function
- Configuring property values using the dot notation

Example The following commands display summary information for the timer object `t`.

```
t = timer

Timer Object: timer-1

   Timer Settings
      ExecutionMode: singleShot
             Period: 1
           BusyMode: drop
            Running: off

   Callbacks
           TimerFcn: []
           ErrorFcn: []
           StartFcn: []
            StopFcn: []
```

This example shows the summary information displayed for an array of timer objects, `t_arr`.

```
disp(t_arr)

Timer Object Array
```

```
Index:  ExecutionMode:  Period:  TimerFcn:           Name:
1       singleShot      1        []                  timer-1
2       singleShot      1        []                  timer-2
```

See Also

`timer`, `get`

Purpose Overloaded method to display an object

Syntax

```
display(X)
```

Description

`display(X)` prints the value of a variable or expression, `X`. MATLAB calls `display(X)` when it interprets a variable or expression, `X`, that is not terminated by a semicolon. For example, `sin(A)` calls `display`, while `sin(A);` does not.

If `X` is an instance of a MATLAB class, then MATLAB calls the `display` method of that class, if such a method exists. If the class has no `display` method or if `X` is not an instance of a MATLAB class, then the MATLAB builtin `display` function is called.

Examples

A typical implementation of `display` calls `disp` to do most of the work and looks like this.

```
function display(X)
if isequal(get(0,'FormatSpacing'),'compact')
   disp([inputname(1) ' =']);
   disp(X)
else
   disp(' ')
   disp([inputname(1) ' =']);
   disp(' ');
   disp(X)
end
```

The expression `magic(3)`, with no terminating semicolon, calls this function as `display(magic(3))`.

```
magic(3)

ans =

     8     1     6
     3     5     7
     4     9     2
```

As an example of a class `display` method, the function below implements the `display` method for objects of the MATLAB class, `polynom`.

```
function display(p)
% POLYNOM/DISPLAY Command window display of a polynom
disp(' ');
disp([inputname(1),' = '])
disp(' ');
disp(['   ' char(p)])
disp(' ');
```

The statement

```
p = polynom([1 0 -2 -5])
```

creates a `polynom` object. Since the statement is not terminated with a semicolon, the MATLAB interpreter calls `display(p)`, resulting in the output

```
p =

    x^3 - 2*x - 5
```

See Also

`disp`, `ans`, `sprintf`, `special characters`

Purpose

Computes the divergence of a vector field

Syntax

```
div = divergence(X,Y,Z,U,V,W)
div = divergence(U,V,W)
div = divergence(X,Y,U,V)
div = divergence(U,V)
```

Description

`div = divergence(X,Y,Z,U,V,W)` computes the divergence of a 3-D vector field `U`, `V`, `W`. The arrays `X`, `Y`, `Z` define the coordinates for `U`, `V`, `W` and must be monotonic and 3-D plaid (as if produced by `meshgrid`).

`div = divergence(U,V,W)` assumes `X`, `Y`, and `Z` are determined by the expression:

```
[X Y Z] = meshgrid(1:n,1:m,1:p)
```

where `[m,n,p] = size(U)`.

`div = divergence(X,Y,U,V)` computes the divergence of a 2-D vector field `U`, `V`. The arrays `X`, `Y` define the coordinates for `U`, `V` and must be monotonic and 2-D plaid (as if produced by `meshgrid`).

`div = divergence(U,V)` assumes `X` and `Y` are determined by the expression:

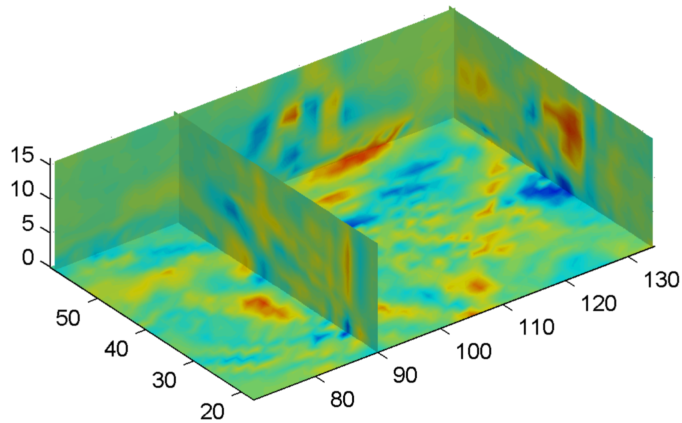
```
[X Y] = meshgrid(1:n,1:m)
```

where `[m,n] = size(U)`.

Examples

This example displays the divergence of vector volume data as slice planes using color to indicate divergence.

```
load wind
div = divergence(x,y,z,u,v,w);
slice(x,y,z,div,[90 134],[59],[0]);
shading interp
daspect([1 1 1])
camlight
```



See Also

`streamtube`, `curl`, `isosurface`

"Volume Visualization" for related functions

Displaying Divergence with Stream Tubes for another example

Purpose

Read an ASCII delimited file into a matrix

Graphical Interface

As an alternative to `dlmread`, use the Import Wizard. To activate the Import Wizard, select **Import data** from the **File** menu.

Syntax

```
M = dlmread(filename,delimiter)
M = dlmread(filename,delimiter,R,C)
M = dlmread(filename,delimiter,range)
```

Description

`M = dlmread(filename,delimiter)` reads numeric data from the ASCII delimited file `filename`, using the specified `delimiter`. A comma (,) is the default delimiter. Use `'\t'` to specify a tab delimiter.

`M = dlmread(filename,delimiter,R,C)` reads numeric data from the ASCII delimited file `filename`, using the specified `delimiter`. The values `R` and `C` specify the row and column where the upper-left corner of the data lies in the file. `R` and `C` are zero based so that `R=0`, `C=0` specifies the first value in the file, which is the upper left corner.

`M = dlmread(filename,delimiter,range)` reads the range specified by `range = [R1 C1 R2 C2]` where `(R1,C1)` is the upper-left corner of the data to be read and `(R2,C2)` is the lower-right corner. `range` can also be specified using spreadsheet notation as in `range = 'A1..B7'`.

Remarks

`dlmread` fills empty delimited fields with zero. Data files having lines that end with a non-space delimiter, such as a semi-colon, produce a result that has an additional last column of zeros.

See Also

`dlmwrite`, `textread`, `csvread`, `csvwrite`, `wk1read`, `wk1write`

dlmwrite

Purpose Write a matrix to an ASCII delimited file

Syntax

```
dlmwrite(filename,M,delimiter)
dlmwrite(filename,M,delimiter,R,C)
```

Description `dlmwrite(filename,M,delimiter)` writes matrix `M` into an ASCII-format file, using `delimiter` to separate matrix elements. The data is written to the upper left-most cell of the spreadsheet `filename`. A comma (,) is the default delimiter. Use `'\t'` to produce tab-delimited files.

`dlmwrite(filename,M,delimiter,R,C)` writes matrix `A` into an ASCII-format file, using `delimiter` to separate matrix elements. The data is written to the spreadsheet `filename`, starting at spreadsheet cell `R` and `C`, where `R` is the row offset and `C` is the column offset. `R` and `C` are zero based so that `R=0`, `C=0` specifies the first value in the file, which is the upper left corner.

Remarks The resulting file is readable by spreadsheet programs.

See Also `dlmread`, `csvwrite`, `csvread`, `wk1write`, `wk1read`

Purpose

Dulmage-Mendelsohn decomposition

Syntax

```
p = dmperm(A)
[p,q,r,s] = dmperm(A)
```

Description

`p = dmperm(A)` if `A` is square and has full rank, returns a row permutation `p` so that `A(p,:)` has nonzero diagonal elements. This permutation is also called a *perfect matching*. If `A` is not square or not full rank, `p` is a vector that identifies a matching of maximum size: for each column `j` of `A`, either `p(j)=0` or `A(p(j),j)` is nonzero.

`[p,q,r,s] = dmperm(A)`, where `A` need not be square or full rank, finds permutations `p` and `q` and index vectors `r` and `s` so that `A(p,q)` is block upper triangular. The kth block has indices `(r(k):r(k+1)-1, s(k):s(k+1)-1)`. When `A` is square and has full rank, `r = s`.

If `A` is not square or not full rank, the first block may have more columns and the last block may have more rows. All other blocks are square and irreducible. `dmperm` permutes nonzeros to the diagonals of square blocks, but does not do this for non-square blocks.

Remarks

If `A` is a reducible matrix, the linear system $Ax = b$ can be solved by permuting `A` to a block upper triangular form, with irreducible diagonal blocks, and then performing block backsubstitution. Only the diagonal blocks of the permuted matrix need to be factored, saving fill and arithmetic in the blocks above the diagonal.

In graph theoretic terms, `dmperm` finds a maximum-size matching in the bipartite graph of `A`, and the diagonal blocks of `A(p,q)` correspond to the strong Hall components of that graph. The output of `dmperm` can also be used to find the connected or strongly connected components of an undirected or directed graph. For more information see Pothen and Fan [].

See Also

`sprank`

References

Pothen, Alex and Chin-Ju Fan, "Computing the Block Triangular Form of a Sparse Matrix," *ACM Transactions on Mathematical Software*, Vol. 16, No. 4, Dec. 1990, pp. 303-324.

doc

Purpose

Display online documentation in MATLAB Help browser

Graphical Interface

As an alternative to the `doc` function, use the Help browser **Search** tab. Set the **Search type** to **Function Name**, type the function name, and click **Go**.

Syntax

```
doc
doc function
doc toolbox/
doc toolbox/function
```

Description

`doc` opens the Help browser, if it is not already running.

`doc function` displays the reference page for the MATLAB function `function` in the Help browser. If `function` is overloaded, `doc` displays the reference page for the first `function` on the search path and lists the overloaded functions in the MATLAB Command Window. If a reference page for the function does not exist, `doc` displays M-file help in the Help browser.

`doc toolbox/` displays the Roadmap page, a summary of the most pertinent documentation for `toolbox`, in the Help browser.

`doc toolbox/function` displays the reference page for `function` that belongs to the specified `toolbox`, in the Help browser.

See Also

`help`, `helpbrowser`, `lookfor`, `type`, `web`

Purpose Display location of help file directory for UNIX platforms

Syntax

```
docopt
[doccmd,options,docpath] = docopt
```

Description `docopt` displays the location of the online help files directory (online documentation location) for UNIX platforms if the `web` function is used with the `-browser` option. It is also used for UNIX platforms that do not support Java GUIs—see the "Release 13 Release Notes" for more information about these platforms. You specify where the online help directory will be located when you install MATLAB. It can be on a disk or CD-ROM drive in your local system. If you relocate your online help file directory, edit the `docopt.m` file, changing the location in it. (For Windows and the UNIX platforms that support Java GUIs, select **File -> Preferences -> Help** to view or change the documentation location.)

`[doccmd,options,docpath] = docopt` displays three strings: `doccmd`, `options`, and `docpath`.

`doccmd`	The function that `doc` uses to display MATLAB documentation. The default is `netscape`.
`options`	Additional configuration options for use with `doccmd`.
`docpath`	The path to the MATLAB online help files. If `docpath` is empty, the `doc` function assumes the help files are in the default location.

Remarks To globally replace the online help file directory location, update `$matlabroot/toolbox/local/docopt.m`.

To override the global setting, copy `$matlabroot/toolbox/local/docopt.m` to `$HOME/matlab/docopt.m` and make changes there. For the changes to take effect in the current MATLAB session, `$HOME/matlab` must be on your MATLAB path.

See Also `doc`, `help`, `helpbrowser`, `helpdesk`, `lookfor`, `type`

docroot

Purpose Get or set root directory for MATLAB help files

Graphical Interface As an alternative to the `docroot` function, select **File -> Preferences -> Help** and set the **Documentation location**.

Syntax

```
docroot
docroot('newdocroot')
docroot(newdocroot, 'cdrom')
```

Description `docroot` displays the current value for `docroot`, the root directory for MATLAB help files. This is the directory where the MATLAB Help browser looks for the online documentation to display.

`docroot('newdocroot')` sets the root directory for MATLAB help files to `newdocroot`, where `newdocroot` is the full pathname to the `help` directory. For example, type `docroot('d:/matlabr13/help')`. One useful application is setting `docroot` in your `startup.m` file.

`docroot('newdocroot', 'cdrom')` sets the root directory for MATLAB help files on the MATLAB documentation CD to `newdocroot`, where `newdocroot` is the full pathname to the `help` directory on your MATLAB documentation CD. For example, type `docroot('z:/help', 'cdrom')`.

Examples You can include a `docroot` statement in your `startup.m` file.

See Also `doc`, `helpbrowser`

Purpose Execute a DOS command and return result

Syntax

```
dos command
status = dos('command')
[status,result] = dos('command')
[status,result] = dos('command','-echo')
```

Description `dos command` calls upon the shell to execute the given command for Windows systems.

`status = dos('command')` returns completion status to the `status` variable.

`[status,result] = dos('command')` in addition to completion status, returns the result of the command to the `result` variable.

`[status,result] = dos('command','-echo')` forces the output to the Command Window, even though it is also being assigned into a variable.

Both console (DOS) programs and Windows programs may be executed, but the syntax causes different results based on the type of programs. Console programs have `stdout` and their output is returned to the result variable. They are always run in an iconified DOS or Command Prompt Window except as noted below. Console programs never execute in the background. Also, MATLAB will always wait for the `stdout` pipe to close before continuing execution. Windows programs may be executed in the background as they have no `stdout`.

The ampersand, `&`, character has special meaning. For console programs this causes the console to open. Omitting this character will cause console programs to run iconically. For Windows programs, appending this character will cause the application to run in the background. MATLAB will continue processing.

Examples The following example performs a directory listing, returning a zero (success) in `s` and the string containing the listing in `w`.

```
[s, w] = dos('dir');
```

To open the DOS 5.0 editor in a DOS window

```
dos('edit &')
```

To open the notepad editor and return control immediately to MATLAB

```
dos('notepad file.m &')
```

The next example returns a one in `s` and an error message in `w` because `foo` is not a valid shell command.

```
[s, w] = dos('foo')
```

This example echoes the results of the `dir` command to the Command Window as it executes as well as assigning the results to w.

```
[s, w] = dos('dir', '-echo');
```

See Also

`!` (exclamation point), `perl`, `system`, `unix`

Purpose Vector dot product

Syntax

```
C = dot(A,B)
C = dot(A,B,dim)
```

Description

`C = dot(A,B)` returns the scalar product of the vectors `A` and `B`. `A` and `B` must be vectors of the same length. When `A` and `B` are both column vectors, `dot(A,B)` is the same as `A'*B`.

For multidimensional arrays `A` and `B`, `dot` returns the scalar product along the first non-singleton dimension of `A` and `B`. `A` and `B` must have the same size.

`C = dot(A,B,dim)` returns the scalar product of `A` and `B` in the dimension `dim`.

Examples

The dot product of two vectors is calculated as shown:

```
a = [1 2 3]; b = [4 5 6];
c = dot(a,b)

c =
       32
```

See Also

`cross`

double

Purpose Convert to double-precision

Syntax `double(X)`

Description `double(x)` returns the double-precision value for `X`. If `X` is already a double-precision array, `double` has no effect.

Remarks `double` is called for the expressions in `for`, `if`, and `while` loops if the expression isn't already double-precision. `double` should be overloaded for any object when it makes sense to convert it to a double-precision value.

Purpose

Drag rectangles with mouse

Syntax

```
[finalrect] = dragrect(initialrect)
[finalrect] = dragrect(initialrect,stepsize)
```

Description

`[finalrect] = dragrect(initialrect)` tracks one or more rectangles anywhere on the screen. The n-by-4 matrix, `initialrect`, defines the rectangles. Each row of `initialrect` must contain the initial rectangle position as `[left bottom width height]` values. `dragrect` returns the final position of the rectangles in `finalrect`.

`[finalrect] = dragrect(initialrect,stepsize)` moves the rectangles in increments of `stepsize`. The lower-left corner of the first rectangle is constrained to a grid of size equal to `stepsize` starting at the lower-left corner of the figure, and all other rectangles maintain their original offset from the first rectangle.

`[finalrect] = dragrect(...)` returns the final positions of the rectangles when the mouse button is released. The default stepsize is `1`.

Remarks

`dragrect` returns immediately if a mouse button is not currently pressed. Use `dragrect` in a `ButtonDownFcn`, or from the command line in conjunction with `waitforbuttonpress` to ensure that the mouse button is down when `dragrect` is called. `dragrect` returns when you release the mouse button.

If the drag ends over a figure window, the positions of the rectangles are returned in that figure's coordinate system. If the drag ends over a part of the screen not contained within a figure window, the rectangles are returned in the coordinate system of the figure over which the drag began

Example

Drag a rectangle that is 50 pixels wide and 100 pixels in height.

```
waitforbuttonpress
point1 = get(gcf,'CurrentPoint') % button down detected
rect = [point1(1,1) point1(1,2) 50 100]
[r2] = dragrect(rect)
```

See Also

`rbbox`, `waitforbuttonpress`

“Selecting Region of Interest” for related functions

drawnow

Purpose Complete pending drawing events

Syntax

```
drawnow
```

Description `drawnow` flushes the event queue and updates the figure window.

Remarks Other events that cause MATLAB to flush the event queue and draw the figure windows include:

- Returning to the MATLAB prompt
- A `pause` statement
- A `waitforbuttonpress` statement
- A `waitfor` statement
- A `getframe` statement
- A `figure` statement

Examples Executing the statements,

```
x = -pi:pi/20:pi;
plot(x,cos(x))
drawnow
title('A Short Title')
grid on
```

as an M-file updates the current figure after executing the `drawnow` function and after executing the final statement.

See Also `waitfor`, `pause`, `waitforbuttonpress`

"Figure Windows" for related functions

Purpose

Search for nearest point

Syntax

```
K = dsearch(x,y,TRI,xi,yi)
K = dsearch(x,y,TRI,xi,yi,S)
```

Description

`K = dsearch(x,y,TRI,xi,yi)` returns the index into `x` and `y` of the nearest point to the point (`xi`,`yi`). `dsearch` requires a triangulation `TRI` of the points `x`,`y` obtained using `delaunay`. If `xi` and `yi` are vectors, `K` is a vector of the same size.

`K = dsearch(x,y,TRI,xi,yi,S)` uses the sparse matrix `S` instead of computing it each time:

```
S = sparse(TRI(:,[1 1 2 2 3 3]),TRI(:,[2 3 1 3 1 2]),1,nxy,nxy)
```

where `nxy = prod(size(x))`.

See Also

`delaunay`, `tsearch`, `voronoi`

Purpose n-D nearest point search

Syntax

```
k = dsearchn(X,T,XI)
k = dsearchn(X,T,XI,outval)
k = dsearchn(X,XI)
[k,d] = dsearchn(X,...)
```

Description `k = dsearchn(X,T,XI)` returns the indices `k` of the closest points in `X` for each point in `XI`. `X` is an `m`-by-`n` matrix representing `m` points in `n`-D space. `XI` is a `p`-by-`n` matrix, representing `p` points in `n`-D space. `T` is a `numt`-by-`n+1` matrix, a tessellation of the data `X` generated by `delaunayn`. The output `k` is a column vector of length `p`.

`k = dsearchn(X,T,XI,outval)` returns the indices `k` of the closest points in `X` for each point in `XI`, unless a point is outside the convex hull. If `XI(J,:)` is outside the convex hull, then `K(J)` is assigned `outval`, a scalar double. `Inf` is often used for `outval`. If `outval` is `[]`, then `k` is the same as in the case `k = dsearchn(X,T,XI)`.

`k = dsearchn(X,XI)` performs the search without using a tessellation. With large `X` and small `XI`, this approach is faster and uses much less memory.

`[k,d] = dsearchn(X,...)` also returns the distances `d` to the closest points. `d` is a column vector of length `p`.

See Also `tsearch`, `dsearch`, `tsearchn`, `griddatan`, `delaunayn`

Purpose

Echo M-files during execution

Syntax

```
echo on
echo off
echo
echo fcnname on
echo fcnname off
echo fcnname
echo on all
echo off all
```

Description

The `echo` command controls the echoing of M-files during execution. Normally, the commands in M-files do not display on the screen during execution. Command echoing is useful for debugging or for demonstrations, allowing the commands to be viewed as they execute.

The `echo` command behaves in a slightly different manner for script files and function files. For script files, the use of `echo` is simple; echoing can be either `on` or `off`, in which case any script used is affected.

`echo on`	Turns on the echoing of commands in all script files.
`echo off`	Turns off the echoing of commands in all script files.
`echo`	Toggles the echo state.

With function files, the use of `echo` is more complicated. If `echo` is enabled on a function file, the file is interpreted, rather than compiled. Each input line is then displayed as it is executed. Since this results in inefficient execution, use `echo` only for debugging.

`echo` *`fcnname`* `on`	Turns on echoing of the named function file.
`echo` *`fcnname`* `off`	Turns off echoing of the named function file.
`echo` *`fcnname`*	Toggles the echo state of the named function file.
`echo on all`	Set echoing on for all function files.
`echo off all`	Set echoing off for all function files.

See Also

`function`

Purpose

Edit or create M-file

Graphical Interface

As an alternative to the `edit` function, select **New** or **Open** from the **File** menu in the MATLAB desktop or any desktop tool.

Syntax

```
edit
edit fun.m
edit file.ext
edit fun1 fun2 fun3 ...
edit class/fun
edit private/fun
edit class/private/fun
```

Description

`edit` opens a new editor window.

`edit fun.m` opens the M-file `fun.m` in the default editor. Note that `fun.m` can be a MATLAB `partialpath` or a complete path. If `fun.m` does not exist, a prompt appears asking if you want to create a new file titled `fun.m`. After you click **Yes**, the Editor/Debugger creates a blank file titled `fun.m`. If you do not want the prompt to appear in this situation, select that check box in the prompt. Then when you type `edit fun.m`, where `fun.m` did not previously exist, a new file called `fun.m` is automatically opened in the Editor. To make the prompt appear, specify it in preferences for "Prompt" on page 7-38.

`edit file.ext` opens the specified file.

`edit fun1 fun2 fun3 ...` opens `fun1.m`, `fun2.m`, `fun3.m`, and so on, in the default editor.

`edit class/fun`, `edit private/fun`, or `edit class/private/fun` can be used to edit a method, private function, or private method (for the class named `class`).

Remarks

To specify the default editor for MATLAB, select **Preferences** from the **File** menu. On the **Editor/Debugger** panel, select the MATLAB Editor/Debugger or specify another.

UNIX Users

If you run MATLAB with the -nodisplay startup option, or run without the DISPLAY environment variable set, edit uses the External Editor command. It does not use the MATLAB Editor/Debugger, but instead uses the default editor defined for your system in $matlabroot/X11/app-defaults/Matlab.

You can specify the editor that the edit function uses or specify editor options by adding the following line to your own .Xdefaults file, located in ~home

```
matlab*externalEditorCommand: $EDITOR -option $FILE
```

where

- $EDITOR is the name of your default editor, for example, emacs; leaving it as $EDITOR means your default system editor will be used.
- -option is a valid option flag you can include for the specified editor.
- **$FILE** means the filename you type with the edit command will open in the specified editor.

For example,

```
emacs $FILE
```

means that when you type edit foo, the file foo will open in the emacs editor.

After adding the line to your .Xdefaults file, you must run the following before starting MATLAB:

```
xrdb -merge ~home/.Xdefaults
```

For the HP 700 platform, the default editor is instead defined in $matlabroot/toolbox/matlab/general/edit.m. To change it, open the file edit.m and edit the line

```
eval( ['!$EDITOR “' file '" &']);
```

See Also open, type

Purpose Find eigenvalues and eigenvectors

Syntax

```
d = eig(A)
d = eig(A,B)
[V,D] = eig(A)
[V,D] = eig(A,'nobalance')
[V,D] = eig(A,B)
[V,D] = eig(A,B,flag)
```

Description

`d = eig(A)` returns a vector of the eigenvalues of matrix `A`.

`d = eig(A,B)` returns a vector containing the generalized eigenvalues, if `A` and `B` are square matrices.

Note If `S` is sparse and symmetric, you can use `d = eig(S)` to returns the eigenvalues of `S`. To request eigenvectors, and in all other cases, use `eigs` to find the eigenvalues or eigenvectors of sparse matrices.

`[V,D] = eig(A)` produces matrices of eigenvalues (`D`) and eigenvectors (`V`) of matrix `A`, so that `A*V = V*D`. Matrix `D` is the *canonical form* of `A`—a diagonal matrix with `A`'s eigenvalues on the main diagonal. Matrix `V` is the *modal matrix*—its columns are the eigenvectors of `A`.

If `W` is a matrix such that `W'*A = D*W'`, the columns of `W` are the *left eigenvectors* of `A` . Use `[W,D] = eig(A.'); W = conj(W)` to compute the left eigenvectors.

`[V,D] = eig(A,'nobalance')` finds eigenvalues and eigenvectors without a preliminary balancing step. Ordinarily, balancing improves the conditioning of the input matrix, enabling more accurate computation of the eigenvectors and eigenvalues. However, if a matrix contains small elements that are really due to roundoff error, balancing may scale them up to make them as significant as the other elements of the original matrix, leading to incorrect eigenvectors. Use the `nobalance` option in this event. See the `balance` function for more details.

`[V,D] = eig(A,B)` produces a diagonal matrix `D` of generalized eigenvalues and a full matrix `V` whose columns are the corresponding eigenvectors so that `A*V = B*V*D`.

`[V,D] = eig(A,B,flag)` specifies the algorithm used to compute eigenvalues and eigenvectors. `flag` can be:

`'chol'`	Computes the generalized eigenvalues of `A` and `B` using the Cholesky factorization of `B`. This is the default for symmetric (Hermitian) `A` and symmetric (Hermitian) positive definite `B`.
`'qz'`	Ignores the symmetry, if any, and uses the QZ algorithm as it would for nonsymmetric (non-Hermitian) `A` and `B`.

Note For `eig(A)`, the eigenvectors are scaled so that the norm of each is 1.0. For `eig(A,B)`, `eig(A,'nobalance')`, and `eig(A,B,flag)`, the eigenvectors are not normalized.

Remarks

The eigenvalue problem is to determine the nontrivial solutions of the equation

$$Ax = \lambda x$$

where A is an `n`-by-`n` matrix, x is a length `n` column vector, and λ is a scalar. The `n` values of λ that satisfy the equation are the *eigenvalues*, and the corresponding values of x are the *right eigenvectors*. In MATLAB, the function `eig` solves for the eigenvalues λ, and optionally the eigenvectors x.

The *generalized* eigenvalue problem is to determine the nontrivial solutions of the equation

$$Ax = \lambda Bx$$

where both A and B are `n`-by-`n` matrices and λ is a scalar. The values of λ that satisfy the equation are the *generalized eigenvalues* and the corresponding values of x are the *generalized right eigenvectors*.

If B is nonsingular, the problem could be solved by reducing it to a standard eigenvalue problem

$$B^{-1}Ax = \lambda x$$

Because B can be singular, an alternative algorithm, called the QZ method, is necessary.

When a matrix has no repeated eigenvalues, the eigenvectors are always independent and the eigenvector matrix V *diagonalizes* the original matrix A if applied as a similarity transformation. However, if a matrix has repeated eigenvalues, it is not similar to a diagonal matrix unless it has a full (independent) set of eigenvectors. If the eigenvectors are not independent then the original matrix is said to be *defective*. Even if a matrix is defective, the solution from eig satisfies A*X = X*D.

Examples

The matrix

```
B = [ 3     -2      -.9    2*eps
     -2      4       1    -eps
     -eps/4  eps/2  -1     0
     -.5    -.5      .1    1   ];
```

has elements on the order of roundoff error. It is an example for which the nobalance option is necessary to compute the eigenvectors correctly. Try the statements

```
[VB,DB] = eig(B)
B*VB - VB*DB
[VN,DN] = eig(B,'nobalance')
B*VN - VN*DN
```

Algorithm

MATLAB uses LAPACK routines to compute eigenvalues and eigenvectors:

Case	Routine
Real symmetric A	DSYEV
Real nonsymmetric A:	
• With preliminary balance step	DGEEV (with SCLFAC = 2 instead of 8 in DGEBAL)
• d = eig(A,'nobalance')	DGEHRD, DHSEQR
• [V,D] = eig(A,'nobalance')	DGEHRD, DORGHR, DHSEQR, DTREVC
Hermitian A	ZHEEV

Case	Routine
Non-Hermitian A:	
• With preliminary balance step	ZGEEV (with SCLFAC = 2 instead of 8 in ZGEBAL)
• d = eig(A,'nobalance')	ZGEHRD, ZHSEQR
• [V,D] = eig(A,'nobalance')	ZGEHRD, ZUNGHR, ZHSEQR, ZTREVC
Real symmetric A, symmetric positive definite B.	DSYGV
Special case: eig(A,B,'qz') for real A, B (same as real nonsymmetric A, real general B)	DGGEV
Real nonsymmetric A, real general B	DGGEV
Complex Hermitian A, Hermitian positive definite B.	ZHEGV
Special case: eig(A,B,'qz') for complex A or B (same as complex non-Hermitian A, complex B)	ZGGEV
Complex non-Hermitian A, complex B	ZGGEV

See Also

balance, condeig, eigs, hess, qz, schur

References

[1] Anderson, E., Z. Bai, C. Bischof, S. Blackford, J. Demmel, J. Dongarra, J. Du Croz, A. Greenbaum, S. Hammarling, A. McKenney, and D. Sorensen, *LAPACK User's Guide* (http://www.netlib.org/lapack/lug/lapack_lug.html), Third Edition, SIAM, Philadelphia, 1999.

Purpose Find a few eigenvalues and eigenvectors of a square large sparse matrix

Syntax

```
d = eigs(A)
d = eigs(A,B)
d = eigs(A,k)
d = eigs(A,B,k)
d = eigs(A,k,sigma)
d = eigs(A,B,k,sigma)
d = eigs(A,k,sigma,options)
d = eigs(A,B,k,sigma,options)
d = eigs(Afun,n)
d = eigs(Afun,n,B)
d = eigs(Afun,n,k)
d = eigs(Afun,n,B,k)
d = eigs(Afun,n,k,sigma)
d = eigs(Afun,n,B,k,sigma)
d = eigs(Afun,n,k,sigma,options)
d = eigs(Afun,n,B,k,sigma,options)
d = eigs(Afun,n,k,sigma,options,p1,p2...)
d = eigs(Afun,n,B,k,sigma,options,p1,p2...)
[V,D] = eigs(A,...)
[V,D] = eigs(Afun,n,...)
[V,D,flag] = eigs(A,...)
[V,D,flag] = eigs(Afun,n,...)
```

Description

`d = eigs(A)` returns a vector of `A`'s six largest magnitude eigenvalues.

`[V,D] = eigs(A)` returns a diagonal matrix `D` of `A`'s six largest magnitude eigenvalues and a matrix `V` whose columns are the corresponding eigenvectors.

`[V,D,flag] = eigs(A)` also returns a convergence flag. If `flag` is `0` then all the eigenvalues converged; otherwise not all converged.

`eigs(A,B)` solves the generalized eigenvalue problem `A*V == B*V*D`. `B` must be symmetric (or Hermitian) positive definite and the same size as `A`. `eigs(A,[],...)` indicates the standard eigenvalue problem `A*V == V*D`.

`eigs(A,k)` and `eigs(A,B,k)` return the `k` largest magnitude eigenvalues.

`eigs(A,k,sigma)` and `eigs(A,B,k,sigma)` return `k` eigenvalues based on *`sigma`*, which can take any of the following values:

scalar (real or complex, including 0)	The eigenvalues closest to *`sigma`*. If `A` is a function, `Afun` must return `Y = (A-sigma*B)\x` (i.e., `Y = A\x` when `sigma = 0`). Note, `B` need only be symmetric (Hermitian) positive semi-definite.
`'lm'`	Largest magnitude (default).
`'sm'`	Smallest magnitude. Same as `sigma = 0`. If `A` is a function, `Afun` must return `Y = A\x`. Note, `B` need only be symmetric (Hermitian) positive semi-definite.

For real symmetric problems, the following are also options:

`'la'`	Largest algebraic (`'lr'` in MATLAB 5)
`'sa'`	Smallest algebraic (`'sr'` in MATLAB 5)
`'be'`	Both ends (one more from high end if `k` is odd)

For nonsymmetric and complex problems, the following are also options:

`'lr'`	Largest real part
`'sr'`	Smallest real part
`'li'`	Largest imaginary part
`'si'`	Smallest imaginary part

Note The MATLAB 5 value `sigma = 'be'` is obsolete for nonsymmetric and complex problems.

---

eigs(A,K,*sigma*,opts) and eigs(A,B,k,*sigma*,opts) specify an options structure. Default values are shown in brackets ({}).

Parameter	Description	Values
options.issym	1 if A or A-*sigma**B represented by Afun is symmetric, 0 otherwise.	[{0} | 1]
options.isreal	1 if A or A-*sigma**B represented by Afun is real, 0 otherwise.	[0 | {1}]
options.tol	Convergence: Ritz estimate residual <= tol*norm(A).	[scalar | {eps}]
options.maxit	Maximum number of iterations.	[integer | {300}]
options.p	Number of basis vectors. p >= 2k (p >= 2k+1 real nonsymmetric) advised. Note: p must satisfy k < p <= n for real symmetric, k+1 < p <= n otherwise.	[integer | 2*k]
options.v0	Starting vector.	Randomly generated by ARPACK
options.disp	Diagnostic information display level.	[0 | {1} | 2]
options.cholB	1 if B is really its Cholesky factor chol(B), 0 otherwise.	[{0} | 1]
options.permB	Permutation vector permB if sparse B is really chol(B(permB,permB)).	[permB | {1:n}]

Note MATLAB 5 options stagtol and cheb are no longer allowed.

`eigs(Afun,n,...)` accepts the function `Afun` instead of the matrix `A`. `y = Afun(x)` should return:

`A*x`	if *sigma* is not specified, or is a string other than `'sm'`
`A\x`	if *sigma* is `0` or `'sm'`
`(A-`*sigma*`*I)\x`	if *sigma* is a nonzero scalar (standard eigenvalue problem). `I` is an identity matrix of the same size as `A`.
`(A-`*sigma*`*B)\x`	if *sigma* is a nonzero scalar (generalized eigenvalue problem)

`n` is the size of `A`. The matrix `A`, `A-`*sigma*`*I` or `A-`*sigma*`*B` represented by `Afun` is assumed to be real and nonsymmetric unless specified otherwise by `opts.isreal` and `opts.issym`. In all the `eigs` syntaxes, `eigs(A,...)` can be replaced by `eigs(Afun,n,...)`.

`eigs(Afun,n,k,`*sigma*`,opts,p1,p2,...)` and `eigs(Afun,n,B,k,`*sigma*`,opts,p1,p2,...)` provide for additional arguments which are passed to `Afun(x,p1,p2,...)`.

Remarks

`d = eigs(A,k)` is not a substitute for

```
d = eig(full(A))
d = sort(d)
d = d(end-k+1:end)
```

but is most appropriate for large sparse matrices. If the problem fits into memory, it may be quicker to use `eig(full(A))`.

Algorithm

`eigs` provides the reverse communication required by the Fortran library ARPACK, namely the routines `DSAUPD`, `DSEUPD`, `DNAUPD`, `DNEUPD`, `ZNAUPD`, and `ZNEUPD`.

Examples

Example 1: This example shows the use of function handles.

```
A = delsq(numgrid('C',15));
d1 = eigs(A,5,'sm');
```

Equivalently, if `dnRk` is the following one-line function:

```
function y = dnRk(x,R,k)
```

```
y = (delsq(numgrid(R,k))) \ x;
```

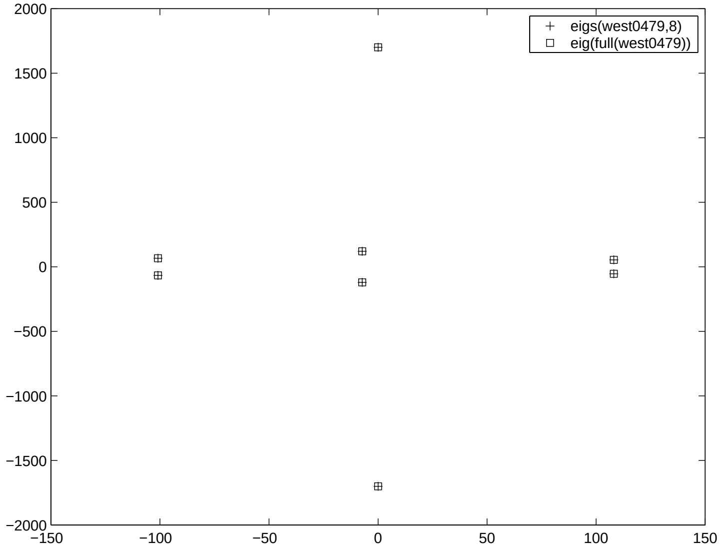
then pass dnRk's additional arguments, 'C' and 15, to eigs.

```
n = size(A,1);
opts.issym = 1;
d2 = eigs(@dnRk,n,5,'sm',opts,'C',15);
```

Example 2: west0479 is a real 479-by-479 sparse matrix with both real and pairs of complex conjugate eigenvalues. eig computes all 479 eigenvalues. eigs easily picks out the largest magnitude eigenvalues.

This plot shows the 8 largest magnitude eigenvalues of west0479 as computed by eig and eigs.

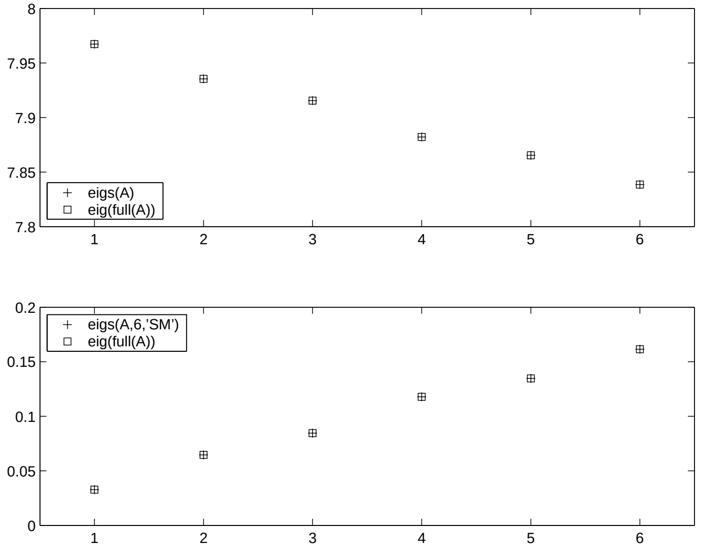
```
load west0479
d = eig(full(west0479))
dlm = eigs(west0479,8)
[dum,ind] = sort(abs(d));
plot(dlm,'k+')
hold on
plot(d(ind(end-7:end)),'ks')
hold off
legend('eigs(west0479,8)','eig(full(west0479))')
```



Example 3: `A = delsq(numgrid('C',30))` is a symmetric positive definite matrix of size 632 with eigenvalues reasonably well-distributed in the interval (0 8), but with 18 eigenvalues repeated at 4. The `eig` function computes all 632 eigenvalues. It computes and plots the six largest and smallest magnitude eigenvalues of `A` successfully with:

```
A = delsq(numgrid('C',30));
d = eig(full(A));
[dum,ind] = sort(abs(d));
dlm = eigs(A);
dsm = eigs(A,6,'sm');

subplot(2,1,1)
plot(dlm,'k+')
hold on
plot(d(ind(end:-1:end-5)),'ks')
hold off
legend('eigs(A)','eig(full(A))',3)
set(gca,'XLim',[0.5 6.5])
```

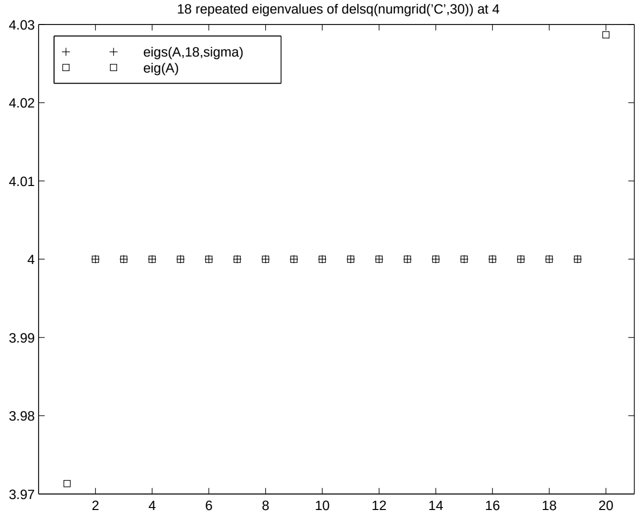
```
subplot(2,1,2)
plot(dsm,'k+')
hold on
plot(d(ind(1:6)),'ks')
hold off
legend('eigs(A,6,''sm'')','eig(full(A))',2)
set(gca,'XLim',[0.5 6.5])
```



However, the repeated eigenvalue at 4 must be handled more carefully. The call `eigs(A,18,4.0)` to compute 18 eigenvalues near 4.0 tries to find eigenvalues of `A - 4.0*I`. This involves divisions of the form `1/(lambda - 4.0)`, where `lambda` is an estimate of an eigenvalue of `A`. As `lambda` gets closer to 4.0, `eigs` fails. We must use `sigma` near but not equal to 4 to find those 18 eigenvalues.

```
sigma = 4 - 1e-6
[V,D] = eigs(A,18,sigma)
```

The plot shows the 20 eigenvalues closest to 4 that were computed by `eig`, along with the 18 eigenvalues closest to `4 - 1e-6` that were computed by `eigs`.



See Also

`arpackc`, `eig`, `svds`

References

[1] Lehoucq, R.B. and D.C. Sorensen, "Deflation Techniques for an Implicitly Re-Started Arnoldi Iteration," *SIAM J. Matrix Analysis and Applications*, Vol. 17, 1996, pp. 789-821.

[2] Lehoucq, R.B., D.C. Sorensen, and C. Yang, *ARPACK Users' Guide: Solution of Large-Scale Eigenvalue Problems with Implicitly Restarted Arnoldi Methods*, SIAM Publications, Philadelphia, 1998.

[3] Sorensen, D.C., "Implicit Application of Polynomial Filters in a k-Step Arnoldi Method," *SIAM J. Matrix Analysis and Applications*, Vol. 13, 1992, pp. 357-385.

ellipj

Purpose

Jacobi elliptic functions

Syntax

```
[SN,CN,DN] = ellipj(U,M)
[SN,CN,DN] = ellipj(U,M,tol)
```

Definition

The Jacobi elliptic functions are defined in terms of the integral:

$$u = \int_0^{\phi} \frac{d\theta}{(1 - m\sin^2\theta)^{\frac{1}{2}}}$$

Then

$$sn(u) = \sin\phi,\ cn(u) = \cos\phi,\ dn(u) = (1 - m\sin^2\phi)^{\frac{1}{2}},\ am(u) = \phi$$

Some definitions of the elliptic functions use the modulus k instead of the parameter m. They are related by

$$k^2 = m = \sin^2\alpha$$

The Jacobi elliptic functions obey many mathematical identities; for a good sample, see [1].

Description

`[SN,CN,DN] = ellipj(U,M)` returns the Jacobi elliptic functions `SN`, `CN`, and `DN`, evaluated for corresponding elements of argument `U` and parameter `M`. Inputs `U` and `M` must be the same size (or either can be scalar).

`[SN,CN,DN] = ellipj(U,M,tol)` computes the Jacobi elliptic functions to accuracy `tol`. The default is `eps`; increase this for a less accurate but more quickly computed answer.

Algorithm

`ellipj` computes the Jacobi elliptic functions using the method of the arithmetic-geometric mean [1]. It starts with the triplet of numbers:

$$a_0 = 1,\ b_0 = (1 - m)^{\frac{1}{2}},\ c_0 = (m)^{\frac{1}{2}}$$

`ellipj` computes successive iterates with

$$a_i = \frac{1}{2}(a_{i-1} + b_{i-1})$$
$$b_i = (a_{i-1}b_{i-1})^{\frac{1}{2}}$$
$$c_i = \frac{1}{2}(a_{i-1} - b_{i-1})$$

Next, it calculates the amplitudes in radians using:

$$\sin(2\phi_{n-1} - \phi_n) = \frac{c_n}{a_n}\sin(\phi_n)$$

being careful to unwrap the phases correctly. The Jacobian elliptic functions are then simply:

$$sn(u) = \sin\phi_0$$
$$cn(u) = \cos\phi_0$$
$$dn(u) = (1 - m \cdot sn(u)^2)^{\frac{1}{2}}$$

Limitations

The `ellipj` function is limited to the input domain $0 \le m \le 1$. Map other values of `M` into this range using the transformations described in [1], equations 16.10 and 16.11. `U` is limited to real values.

See Also

`ellipke`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, Dover Publications, 1965, 17.6.

ellipke

Purpose

Complete elliptic integrals of the first and second kind

Syntax

```
K = ellipke(M)
[K,E] = ellipke(M)
[K,E] = ellipke(M,tol)
```

Definition

The *complete* elliptic integral of the first kind [1] is

$$K(m) = F(\pi/2|m)$$

where F, the elliptic integral of the first kind, is

$$K(m) = \int_0^1 [(1-t^2)(1-mt^2)]^{\frac{-1}{2}}\,dt = \int_0^{\frac{\pi}{2}} (1-m\sin^2\theta)^{\frac{-1}{2}}\,d\theta$$

The complete elliptic integral of the second kind

$$E(m) = E(K(m)) = E\langle\pi/2|m\rangle$$

is

$$E(m) = \int_0^1 (1-t^2)^{\frac{-1}{2}}(1-mt^2)^{\frac{1}{2}}\,dt = \int_0^{\frac{\pi}{2}} (1-m\sin^2\theta)^{\frac{1}{2}}\,d\theta$$

Some definitions of `K` and `E` use the modulus k instead of the parameter m. They are related by

$$k^2 = m = \sin^2\alpha$$

Description

`K = ellipke(M)` returns the complete elliptic integral of the first kind for the elements of `M`.

`[K,E] = ellipke(M)` returns the complete elliptic integral of the first and second kinds.

`[K,E] = ellipke(M,tol)` computes the Jacobian elliptic functions to accuracy `tol`. The default is `eps`; increase this for a less accurate but more quickly computed answer.

Algorithm

`ellipke` computes the complete elliptic integral using the method of the arithmetic-geometric mean described in [1], section 17.6. It starts with the triplet of numbers

$$a_0 = 1,\ b_0 = (1-m)^{\frac{1}{2}},\ c_0 = (m)^{\frac{1}{2}}$$

`ellipke` computes successive iterations of a_i, b_i, and c_i with

$$\begin{aligned} a_i &= \frac{1}{2}(a_{i-1} + b_{i-1}) \\ b_i &= (a_{i-1}b_{i-1})^{\frac{1}{2}} \\ c_i &= \frac{1}{2}(a_{i-1} - b_{i-1}) \end{aligned}$$

stopping at iteration n when $cn \approx 0$, within the tolerance specified by `eps`. The complete elliptic integral of the first kind is then

$$K(m) = \frac{\pi}{2a_n}$$

Limitations

`ellipke` is limited to the input domain $0 \le m \le 1$.

See Also

`ellipj`

References

[1] Abramowitz, M. and I.A. Stegun, *Handbook of Mathematical Functions*, Dover Publications, 1965, 17.6.

ellipsoid

Purpose Generate ellipsoid

Syntax

```
[x,y,z] = ellipsoid(xc,yc,zc,xr,yr,zr,n)
[x,y,z] = ellipsoid(xc,yc,zc,xr,yr,zr)
ellipsoid(...)
```

Description `[x,y,z] = ellipsoid(xc,yc,zc,xr,yr,zr,n)` generates three `n+1`-by-`n+1` matrices so that `surf(x,y,z)` produces an ellipsoid with center `(xc,yc,zc)` and radii `(xr,yr,zr)`.

`[x,y,z] = ellipsoid(xc,yc,zc,xr,yr,zr)` uses `n = 20`.

`ellipsoid(...)` with no output arguments graphs the ellipsoid as a surface.

Algorithm `ellipsoid` generates the data using the following equation:

$$\frac{(x-xc)^2}{xr^2}+\frac{(y-yc)^2}{yr^2}+\frac{(z-zc)^2}{zr^2}$$

See Also `cylinder`, `sphere`, `surf`

"Polygons and Surfaces" for related functions

Purpose

Conditionally execute statements

Syntax

```
if expression
    statements1
else
    statements2
end
```

Description

`else` is used to delineate an alternate block of statements. If *`expression`* evaluates as `false`, MATLAB executes the one or more commands denoted here as *`statements2`*.

A `true` expression has either a logical true or nonzero value. For nonscalar expressions, (for example, "if (matrix A is less than matrix B)"), `true` means that every element of the resulting matrix has a logical true or nonzero value.

Expressions usually involve relational operations such as `(count < limit)` or `isreal(A)`. Simple expressions can be combined by logical operators (&,|,~) into compound expressions such as: `(count < limit) & ((height - offset) >= 0)`.

See `if` for more information.

Examples

In this example, if both of the conditions are not satisfied, then the student fails the course.

```
if ((attendance >= 0.90) & (grade_average >= 60))
   pass = 1;
else
   fail = 1;
end;
```

See Also

`if`, `elseif`, `end`, `for`, `while`, `switch`, `break`, `return`, `relational_operators`, `logical_operators`

elseif

Purpose Conditionally execute statements

Syntax

```
if expression1
   statements1
elseif expression2
   statements2
end
```

Description If *expression1* evaluates as `false` and *expression2* as `true`, MATLAB executes the one or more commands denoted here as *statements2*.

A `true` expression has either a logical true or nonzero value. For nonscalar expressions, (for example, is matrix A less then matrix B), `true` means that every element of the resulting matrix has a logical true or nonzero value.

Expressions usually involve relational operations such as `(count < limit)` or `isreal(A)`. Simple expressions can be combined by logical operators (&,|,~) into compound expressions such as: `(count < limit) & ((height - offset) >= 0)`.

See `if` for more information.

Remarks `else if`, with a space between the `else` and the `if`, differs from `elseif`, with no space. The former introduces a new, nested `if`, which must have a matching `end`. The latter is used in a linear sequence of conditional statements with only one terminating `end`.

The two segments shown below produce identical results. Exactly one of the four assignments to `x` is executed, depending upon the values of the three logical expressions, `A`, `B`, and `C`.

```
if A
   x = a
else
   if B
      x = b
   else
      if C
         x = c
      else
         x = d
```

```
if A
   x = a
elseif B
   x = b
elseif C
   x = c
else
   x = d
end
```

```
        end
    end
end
```

Examples

Here is an example showing if, else, and elseif.

```
for m = 1:k
    for n = 1:k
        if m == n
            a(m,n) = 2;
        elseif abs(m-n) == 2
            a(m,n) = 1;
        else
            a(m,n) = 0;
        end
    end
end
```

For k=5 you get the matrix

```
a =

     2     0     1     0     0
     0     2     0     1     0
     1     0     2     0     1
     0     1     0     2     0
     0     0     1     0     2
```

See Also

if, else, end, for, while, switch, break, return, relational_operators, logical_operators

Purpose Terminate for, while, switch, try, and if statements or indicate last index

Syntax

```
while expression% (or if, for, or try)
   statements
end

B = A(index:end,index)
```

Description

end is used to terminate for, while, switch, try, and if statements. Without an end statement, for, while, switch, try, and if wait for further input. Each end is paired with the closest previous unpaired for, while, switch, try, or if and serves to delimit its scope.

The end command also serves as the last index in an indexing expression. In that context, end = (size(x,k)) when used as part of the kth index. Examples of this use are X(3:end) and X(1,1:2:end-1). When using end to grow an array, as in X(end+1)=5, make sure X exists first.

You can overload the end statement for a user object by defining an end method for the object. The end method should have the calling sequence end(obj,k,n), where obj is the user object, k is the index in the expression where the end syntax is used, and n is the total number of indices in the expression. For example, consider the expression

```
A(end-1,:)
```

MATLAB will call the end method defined for A using the syntax

```
end(A,1,2)
```

Examples

This example shows end used with the for and if statements.

```
for k = 1:n
   if a(k) == 0
       a(k) = a(k) + 2;
    end
end
```

In this example, end is used in an indexing expression.

```
A = magic(5)
```

```
A =

    17    24     1     8    15
    23     5     7    14    16
     4     6    13    20    22
    10    12    19    21     3
    11    18    25     2     9

B = A(end,2:end)

B =

    18    25     2     9
```

See Also `break`, `for`, `if`, `return`, `switch`, `try`, `while`

eomday

Purpose End of month

Syntax

```
E = eomday(Y,M)
```

Description `E = eomday(Y,M)` returns the last day of the year and month given by corresponding elements of arrays `Y` and `M`.

Examples Because 1996 is a leap year, the statement `eomday(1996,2)` returns `29`.

To show all the leap years in this century, try:

```
y = 1900:1999;
E = eomday(y,2*ones(length(y),1)');
y(find(E==29))'

ans =
  Columns 1 through 6
       1904       1908       1912       1916       1920       1924

  Columns 7 through 12
       1928       1932       1936       1940       1944       1948

  Columns 13 through 18
       1952       1956       1960       1964       1968       1972

  Columns 19 through 24
       1976       1980       1984       1988       1992       1996
```

See Also `datenum`, `datevec`, `weekday`

Purpose Floating-point relative accuracy

Syntax

```
eps
```

Description `eps` returns the distance from 1.0 to the next largest floating-point number.

The value `eps` is a default tolerance for `pinv` and `rank`, as well as several other MATLAB functions. `eps = 2^(-52)`, which is roughly `2.22e-16`.

See Also `realmax`, `realmin`

erf, erfc, erfcx, erfinv, erfcinv

Purpose Error functions

Syntax

`Y = erf(X)`	Error function
`Y = erfc(X)`	Complementary error function
`Y = erfcx(X)`	Scaled complementary error function
`X = erfinv(Y)`	Inverse error function
`X = erfcinv(Y)`	Inverse complementary error function

Definition The error function `erf(X)` is twice the integral of the Gaussian distribution with 0 mean and variance of $1/2$.

$$\operatorname{erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt$$

The complementary error function `erfc(X)` is defined as

$$\operatorname{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2} dt = 1 - \operatorname{erf}(x)$$

The scaled complementary error function `erfcx(X)` is defined as

$$\operatorname{erfcx}(x) = e^{x^2} \operatorname{erfc}(x)$$

For large `X`, `erfcx(X)` is approximately $\left(\frac{1}{\sqrt{\pi}}\right)\frac{1}{x}$

Description `Y = erf(X)` returns the value of the error function for each element of real array `X`.

`Y = erfc(X)` computes the value of the complementary error function.

`Y = erfcx(X)` computes the value of the scaled complementary error function.

`X = erfinv(Y)` returns the value of the inverse error function for each element of `Y`. Elements of `Y` must be in the interval `[-1 1]`. The function `erfinv` satisfies $y = \operatorname{erf}(x)$ for $-1 \le y \le 1$ and $-\infty \le x \le \infty$.

`X = erfcinv(Y)` returns the value of the inverse of the complementary error function for each element of `Y`. Elements of `Y` must be in the interval `[0 2]`. The function `erfcinv` satisfies $y = \operatorname{erfc}(x)$ for $2 \ge y \ge 0$ and $-\infty \le x \le \infty$.

Remarks

The relationship between the complementary error function `erfc` and the standard normal probability distribution returned by the Statistics Toolbox function `normcdf` is

$$\mathrm{normcdf}(x) = 0.5 * \mathrm{erfc}(-x/\sqrt{2})$$

The relationship between the inverse complementary error function `erfcinv` and the inverse standard normal probability distribution returned by the Statistics Toolbox function `norminv` is

$$\mathrm{norminv}(p) = -\sqrt{2} * \mathrm{erfcinv}(2p)$$

Examples

`erfinv(1)` is `Inf`

`erfinv(-1)` is `-Inf`.

For `abs(Y) > 1`, `erfinv(Y)` is `NaN`.

Algorithms

For the error functions, the MATLAB code is a translation of a Fortran program by W. J. Cody, Argonne National Laboratory, NETLIB/SPECFUN, March 19, 1990. The main computation evaluates near-minimax rational approximations from [1].

For the inverse of the error function, rational approximations accurate to approximately six significant digits are used to generate an initial approximation, which is then improved to full accuracy by one step of Halley's method.

References

[1] Cody, W. J., "Rational Chebyshev Approximations for the Error Function," *Math. Comp.*, pgs. 631-638, 1969

Purpose Display error messages

Syntax

```
error('message')
error('message',a1,a2, ...)
error('message_id','message')
error('message_id','message',a1,a2,...)
```

Description

`error('message')` displays an error message and returns control to the keyboard. The error message contains the input string `message`.

The `error` command has no effect if `message` is a null string.

`error('message',a1,a2,...)` displays a message string that contains formatting conversion characters, such as those used with the MATLAB `sprintf` function. Each conversion character in `message` is converted to one of the values `a1, a2, ...` in the argument list.

Note MATLAB converts special characters (like `\n` and `%d`) in the error message string only when you specify more than one input argument with `error`. See Example 3 below.

`error('message_id','message')` attaches a unique message identifier, or `message_id`, to the error message. The identifier enables you to better identify the source of an error. See “Message Identifiers” and “Using Message Identifiers with lasterr” in the MATLAB documentation for more information on the `message_id` argument and how to use it.

`error('message_id','message',a1,a2, ...)` includes formatting conversion characters in `message`, and the character translations `a1, a2, ...`

Examples

Example 1

The `error` function provides an error return from M-files:

```
function foo(x,y)
if nargin ~= 2
     error('Wrong number of input arguments')
end
```

The returned error message looks like this:

```
foo(pi)

??? Error using ==> foo
Wrong number of input arguments
```

Example 2

Specify a message identifier and error message string with `error`:

```
error('MyToolbox:angleTooLarge', ...
      'The angle specified must be less than 90 degrees.');
```

In your error handling code, use `lasterr` to determine the message identifier and error message string for the failing operation:

```
[errmsg, msgid] = lasterr
errmsg =
   The angle specified must be less than 90 degrees.
msgid =
   MyToolbox:angleTooLarge
```

Example 3

MATLAB converts special characters (like `\n` and `%d`) in the error message string only when you specify more than one input argument with `error`. In the single argument case shown below, `\n` is taken to mean `backslash-n`. It is not converted to a newline character:

```
error('In this case, the newline \n is not converted.')
??? In this case, the newline \n is not converted.
```

But, when more than one argument is specified, MATLAB does convert special characters. This holds true regardless of whether the additional argument supplies conversion values or is a message identifier:

```
error('ErrorTests:convertTest', ...
      'In this case, the newline \n is converted.')
??? In this case, the newline
 is converted.
```

See Also

`lasterr`, `lasterror`, `rethrow`, `errordlg`, `warning`, `lastwarn`, `warndlg`, `dbstop`, `disp`, `sprintf`

errorbar

Purpose Plot error bars along a curve

Syntax

```
errorbar(Y,E)
errorbar(X,Y,E)
errorbar(X,Y,L,U)
errorbar(...,LineSpec)
h = errorbar(...)
```

Description Error bars show the confidence level of data or the deviation along a curve.

`errorbar(Y,E)` plots `Y` and draws an error bar at each element of `Y`. The error bar is a distance of `E(i)` above and below the curve so that each bar is symmetric and `2*E(i)` long.

`errorbar(X,Y,E)` plots `X` versus `Y` with symmetric error bars `2*E(i)` long. `X`, `Y`, `E` must be the same size. When they are vectors, each error bar is a distance of `E(i)` above and below the point defined by `(X(i),Y(i))`. When they are matrices, each error bar is a distance of `E(i,j)` above and below the point defined by `(X(i,j),Y(i,j))`.

`errorbar(X,Y,L,U)` plots `X` versus `Y` with error bars `L(i)+U(i)` long specifying the lower and upper error bars. `X`, `Y`, `L`, and `U` must be the same size. When they are vectors, each error bar is a distance of `L(i)` below and `U(i)` above the point defined by `(X(i),Y(i))`. When they are matrices, each error bar is a distance of `L(i,j)` below and `U(i,j)` above the point defined by `(X(i,j),Y(i,j))`.

`errorbar(...,LineSpec)` draws the error bars using the line type, marker symbol, and color specified by `LineSpec`.

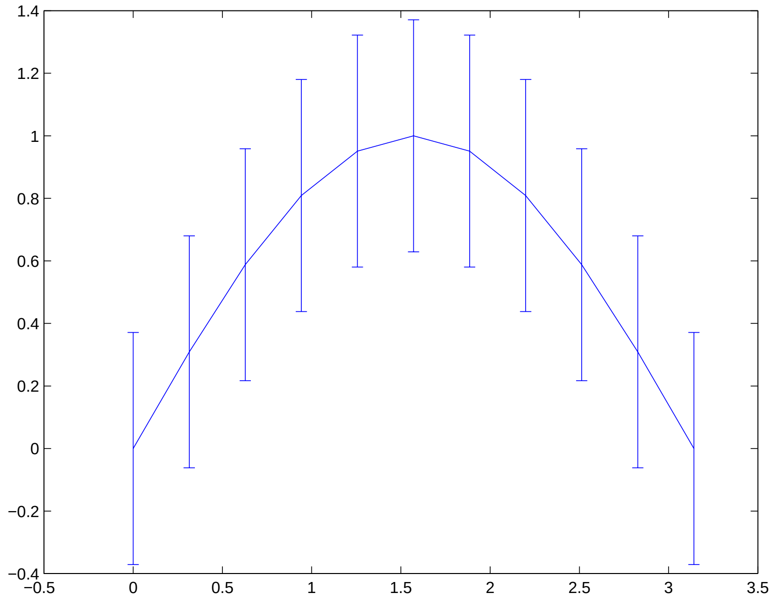
`h = errorbar(...)` returns a vector of handles to line graphics objects.

Remarks When the arguments are all matrices, `errorbar` draws one line per matrix column. If `X` and `Y` are vectors, they specify one curve.

Examples Draw symmetric error bars that are two standard deviation units in length.

```
X = 0:pi/10:pi;
Y = sin(X);
E = std(Y)*ones(size(X));
```

```
errorbar(X,Y,E)
```



See Also

`LineSpec`, `plot`, `std`

"Basic Plots and Graphs" for related functions

errordlg

Purpose Create and display an error dialog box

Syntax

```
errordlg
errordlg('errorstring')
errordlg('errorstring','dlgname')
errordlg('errorstring','dlgname','on')
h = errordlg(...)
```

Description `errordlg` creates an error dialog box, or if the named dialog exists, `errordlg` pops the named dialog in front of other windows.

`errordlg` displays a dialog box named `'Error Dialog'` that contains the string `'This is the default error string.'`

`errordlg('errorstring')` displays a dialog box named `'Error Dialog'` that contains the string `'errorstring'`.

`errordlg('errorstring','dlgname')` displays a dialog box named `'dlgname'` that contains the string `'errorstring'`.

`errordlg('errorstring','dlgname','on')` specifies whether to replace an existing dialog box having the same name. `'on'` brings an existing error dialog having the same name to the foreground. In this case, `errordlg` does not create a new dialog.

`h = errordlg(...)` returns the handle of the dialog box.

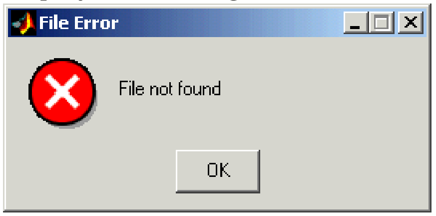
Remarks MATLAB sizes the dialog box to fit the string `'errorstring'`. The error dialog box has an OK pushbutton and remains on the screen until you press the OK button or the **Return** key. After pressing the button, the error dialog box disappears.

The appearance of the dialog box depends on the windowing system you use.

Examples The function

```
errordlg('File not found','File Error');
```

displays this dialog box:



See Also

`dialog`, `helpdlg`, `msgbox`, `questdlg`, `warndlg`

"Predefined Dialog Boxes" for related functions

etime

Purpose

Elapsed time

Syntax

```
e = etime(t2,t1)
```

Description

`e = etime(t2,t1)` returns the time in seconds between vectors `t1` and `t2`. The two vectors must be six elements long, in the format returned by `clock`:

```
T = [Year Month Day Hour Minute Second]
```

Examples

Calculate how long a 2048-point real FFT takes.

```
x = rand(2048,1);
t = clock; fft(x); etime(clock,t)
ans =
      0.4167
```

Limitations

As currently implemented, the `etime` function fails across month and year boundaries. Since `etime` is an M-file, you can modify the code to work across these boundaries if needed.

See Also

`clock`, `cputime`, `tic`, `toc`

Purpose Elimination tree

Syntax

```
p = etree(A)
p = etree(A,'col')
p = etree(A,'sym')
[p,q] = etree(...)
```

Description

`p = etree(A)` returns an elimination tree for the square symmetric matrix whose upper triangle is that of `A`. `p(j)` is the parent of column `j` in the tree, or `0` if `j` is a root.

`p = etree(A,'col')` returns the elimination tree of `A'*A`.

`p = etree(A,'sym')` is the same as `p = etree(A)`.

`[p,q] = etree(...)` also returns a postorder permutation `q` of the tree.

See Also

`treelayout`, `treeplot`, `etreeplot`

etreeplot

Purpose Plot elimination tree

Syntax

```
etreeplot(A)
etreeplot(A,nodeSpec,edgeSpec)
```

Description `etreeplot(A)` plots the elimination tree of `A` (or `A+A'`, if non-symmetric).

`etreeplot(A,nodeSpec,edgeSpec)` allows optional parameters `nodeSpec` and `edgeSpec` to set the node or edge color, marker, and linestyle. Use `''` to omit one or both.

See Also `etree`, `treeplot`, `treelayout`

Purpose Execute a string containing a MATLAB expression

Syntax

```
eval(expression)
eval(expression,catch_expr)
[a1,a2,a3,...] = eval(function(b1,b2,b3,...))
```

Description `eval(expression)` executes `expression`, a string containing any valid MATLAB expression. You can construct `expression` by concatenating substrings and variables inside square brackets:

```
expression = [string1,int2str(var),string2,...]
```

`eval(expression,catch_expr)` executes `expression` and, if an error is detected, executes the `catch_expr` string. If `expression` produces an error, the error string can be obtained with the `lasterr` function. This syntax is useful when `expression` is a string that must be constructed from substrings. If this is not the case, use the `try...catch` control flow statement in your code.

`[a1,a2,a3,...] = eval(function(b1,b2,b3,...))` executes `function` with arguments `b1,b2,b3,...`, and returns the results in the specified output variables.

Remarks Using the `eval` output argument list is recommended over including the output arguments in the expression string. The first syntax below avoids strict checking by the MATLAB parser and can produce untrapped errors and other unexpected behavior.

```
eval('[a1,a2,a3,...] = function(var)')      % not recommended

[a1,a2,a3,...] = eval('function(var)')      % recommended syntax
```

Examples This `for` loop generates a sequence of 12 matrices named `M1` through `M12`:

```
for n = 1:12

      magic_str = ['M',int2str(n),' = magic(n)'];
      eval(magic_str)

end
```

This example uses a function showdemo that runs a MATLAB demo selected by the user. If an error is encountered, a message is displayed that names the demo that failed.

```
function showdemo(demos)
errstring = 'Error running demo: ';
n = input('Select a demo number: ');
eval(demos(n,:),'[errstring demos(n,:)]')
% ----- end of file showdemo.m -----

D = ['odedemo'; 'quademo'; 'fitdemo'];
showdemo(D)
Select a demo number: 2

ans =

Error running demo: quademo
```

The next example executes the size function on a 3-dimensional array, returning the array dimensions in output variables d1, d2, and d3.

```
A = magic(4);
A(:,:,2) = A';

[d1,d2,d3] = eval('size(A)')

d1 =
     4

d2 =
     4

d3 =
     2
```

See Also

assignin, catch, evalin, feval, lasterr, try

Purpose Evaluate MATLAB expression with capture

Syntax

```
T = evalc(S)
T = evalc(s1,s2)
[T,X,Y,Z,...] = evalc(S)
```

Description `T = evalc(S)` is the same as `eval(S)` except that anything that would normally be written to the command window is captured and returned in the character array `T` (lines in `T` are separated by `\n` characters).

`T = evalc(s1,s2)` is the same as `eval(s1,s2)` except that any output is captured into `T`.

`[T,X,Y,Z,...] = evalc(S)` is the same as `[X,Y,Z,...] = eval(S)` except that any output is captured into `T`.

Remark When you are using `evalc`, `diary`, `more`, and `input` are disabled.

See Also `diary`, `eval`, `evalin`, `input`, `more`

evalin

Purpose

Execute a string containing a MATLAB expression in a workspace

Syntax

```
evalin(ws,expression)
[a1,a2,a3,...] = evalin(ws,expression)
evalin(ws,expression,catch_expr)
```

Description

`evalin(ws,`*`expression`*`)` executes *`expression`*, a string containing any valid MATLAB expression, in the context of the workspace `ws`. `ws` can have a value of `'base'` or `'caller'` to denote the MATLAB base workspace or the workspace of the caller function. You can construct *`expression`* by concatenating substrings and variables inside square brackets:

```
expression = [string1,int2str(var),string2,...]
```

`[a1,a2,a3,...] = evalin(ws,`*`expression`*`)` executes *`expression`* and returns the results in the specified output variables. Using the `evalin` output argument list is recommended over including the output arguments in the expression string:

```
evalin(ws,'[a1,a2,a3,...] = function(var)')
```

The above syntax avoids strict checking by the MATLAB parser and can produce untrapped errors and other unexpected behavior.

`evalin(ws,`*`expression,catch_expr`*`)` executes *`expression`* and, if an error is detected, executes the *`catch_expr`* string. If *`expression`* produces an error, the error string can be obtained with the `lasterr` function. This syntax is useful when *`expression`* is a string that must be constructed from substrings. If this is not the case, use the `try...catch` control flow statement in your code.

Remarks

The MATLAB base workspace is the workspace that is seen from the MATLAB command line (when not in the debugger). The caller workspace is the workspace of the function that called the M-file. Note, the base and caller workspaces are equivalent in the context of an M-file that is invoked from the MATLAB command line.

Examples

This example extracts the value of the variable `var` in the MATLAB base workspace and captures the value in the local variable `v`:

```
v = evalin('base','var');
```

Limitation

evalin cannot be used recursively to evaluate an expression. For example, a sequence of the form `evalin('caller','evalin(''caller'',''x'')')` doesn't work.

See Also

`assignin`, `catch`, `eval`, `feval`, `lasterr`, `try`

eventlisteners (COM)

Purpose Return a list of events attached to listeners

Syntax `eventlisteners(h)`

Arguments `h`
Handle for a MATLAB COM control object.

Description `eventlisteners` lists any events, along with their callback or event handler routines, that have been registered with control, `h`. The function returns a cell array of strings, with each row containing the name of a registered event and the handler routine for that event. If the control has no registered events, then `eventlisteners` returns an empty cell array.

Events and their callback or event handler routines must be registered in order for the control to respond to them. You can register events either when you create the control, using `actxcontrol`, or at any time afterwards, using `registerevent`.

Examples Create an `mwsamp` control, registering only the `Click` event. `eventlisteners` returns the name of the event and its event handler routine, `myclick`:

```
f = figure('pos', [100 200 200 200]);
h = actxcontrol('mwsamp.mwsampctrl.2', [0 0 200 200], f, ...
    {'Click' 'myclick'});

eventlisteners(h)
ans =
    'click'    'myclick'
```

Register two more events: `DblClick` and `MouseDown`. `eventlisteners` returns the names of the three registered events along with their respective handler routines:

```
registerevent(h, {'DblClick', 'my2click'; ...
    'MouseDown' 'mymoused'});

eventlisteners(h)
ans =
    'click'        'myclick'
    'dblclick'     'my2click'
```

```
     'mousedown'     'mymoused'
```

Now unregister all events for the control, and `eventlisteners` returns an empty cell array, indicating that no events have been registered for the control:

```
unregisterallevents(h)

eventlisteners(h)
ans =
     {}
```

See Also

`events`, `registerevent`, `unregisterevent`, `unregisterallevents`, `isevent`

events (COM)

Purpose Return a list of events that the control can trigger

Syntax

```
events(h)
```

Arguments

`h`
Handle for a MATLAB COM control object.

Description Returns a structure array containing all events, both registered and unregistered, known to the control, and the function prototype used when calling the event handler routine. For each array element, the structure field is the event name and the contents of that field is the function prototype for that event's handler.

Note The `send` function is identical to `events`, but `send` will be made obsolete in a future release.

Examples Create an `mwsamp` control and list all events:

```
f = figure ('pos', [100 200 200 200]);
h = actxcontrol ('mwsamp.mwsampctrl.2', [0 0 200 200], f);

events(h)
   Click = void Click()
   DblClick = void DblClick()
   MouseDown = void MouseDown(int16 Button, int16 Shift,
      Variant x, Variant y)
```

Or assign the output to a variable and get one field of the returned structure:

```
ev = events(h);

ev.MouseDown
ans =
void MouseDown(int16 Button, int16 Shift, Variant x, Variant y)
```

See Also `isevent`, `eventlisteners`, `registerevent`, `unregisterevent`, `unregisterallevents`

In the following example, exist returns 8 on the Java class, Welcome, and returns 2 on the Java class file, Welcome.class.

```
exist Welcome
ans =
     8

exist javaclasses/Welcome.class
ans =
     2
```

indicates there is a Java class Welcome and a Java class file Welcome.class.

The following example indicates that testresults is both a variable in the workspace and a directory on the search path:

```
exist('testresults','var')
ans =
     1

exist('testresults','dir')
ans =
     7
```

See Also

dir, help, lookfor, partialpath, what, which, who

Purpose Check if a variable or file exists

Graphical Interface As an alternative to the `exist` function, use the Workspace browser or the Current Directory Browser.

Syntax

```
exist item
exist item kind
a = exist('item',...)
```

Description `exist item` returns the status of the variable or file, `item`:

0	If `item` does not exist.
1	If the variable `item` exists in the workspace.
2	If `item` is an M-file or a file of unknown type.
3	If `item` is a MEX-file on your MATLAB search path.
4	If `item` is an MDL-file on your MATLAB search path.
5	If `item` is a built-in MATLAB function.
6	If `item` is a P-file on your MATLAB search path.
7	If `item` is a directory.
8	If `item` is a Java class.

If `item` specifies a filename, that filename may include an extension to preclude conflicting with other similar filenames. For example, `exist('file.ext')`.

MEX, MDL, and P-files must be on the MATLAB search path for `exist` to return the values shown above. If `item` is found, but is not on the MATLAB search path, `exist('item')` returns `2`, because it considers `item` to be an unknown file type.

Any other file type or directory specified by `item` is not required to be on the MATLAB search path to be recognized by `exist`. If the file or directory is not on the search path, then `item` must specify either a full pathname, a partial pathname relative to `MATLABPATH`, or a partial pathname relative to your current directory.

If `item` is a Java class, then `exist('item')` returns an `8`. However, if `item` is a Java class file, then `exist('item')` returns a `2`.

`exist item` *`kind`* returns the status of `item` for the specified *`kind`*. If `item` of type *`kind`* does not exist, it returns `0`. The *`kind`* argument may be one of the following:

`builtin`	Checks only for built-in functions.
`class`	Checks only for Java classes.
`dir`	Checks only for directories.
`file`	Checks only for files or directories.
`var`	Checks only for variables.

`a = exist('item',...)` returns the status of the variable or file in variable `a`.

Remarks

To check for the existence of more than one variable, use the `ismember` function. For example,

```
a = 5.83;
c = 'teststring';
ismember({'a','b','c'},who)

ans =

     1     0     1
```

Examples

This example uses `exist` to check whether a MATLAB function is a built-in function or a file:

```
type = exist('plot')
type =
     5
```

This indicates that `plot` is a built-in function.

exit

Purpose Terminate MATLAB (same as `quit`)

Graphical Interface As an alternative to the `exit` function, select **Exit MATLAB** from the **File** menu or click the close box in the MATLAB desktop.

Syntax

```
exit
```

Description `exit` ends the current MATLAB session. It is the same as `quit`. See `quit` for termination options.

See Also `finish`, `quit`

Purpose Exponential

Syntax

```
Y = exp(X)
```

Description The `exp` function is an elementary function that operates element-wise on arrays. Its domain includes complex numbers.

`Y = exp(X)` returns the exponential for each element of `X`. For complex $z = x + i*y$, it returns the complex exponential $e^z = e^x(\cos(y) + i\sin(y))$.

Remark Use `expm` for matrix exponentials.

See Also `expm`, `log`, `log10`, `expint`

expint

Purpose Exponential integral

Syntax

```
Y = expint(X)
```

Definitions The exponential integral computed by this function is defined as

$$E_1(x) = \int_x^{\infty} \frac{e^{-t}}{t} dt$$

Another common definition of the exponential integral function is the Cauchy principal value integral

$$Ei(x) = \int_{-\infty}^{x} \frac{e^t}{t} dt$$

which, for real positive `x`, is related to `expint` as

$$E_1(-x) = -Ei(x) - i\pi$$

Description `Y = expint(X)` evaluates the exponential integral for each element of `X`.

References

[1] Abramowitz, M. and I. A. Stegun. *Handbook of Mathematical Functions*. Chapter 5, New York: Dover Publications, 1965.

Purpose Matrix exponential

Syntax

```
Y = expm(X)
```

Description `Y = expm(X)` raises the constant e to the matrix power `X`. The `expm` function produces complex results if `X` has nonpositive eigenvalues.

Use `exp` for the element-by-element exponential.

Algorithm `expm` is a built-in function that uses the Padé approximation with scaling and squaring. You can see the coding of this algorithm in the `expm1` demo.

Note The `expm1`, `expm2`, and `expm3` demos illustrate the use of Padé approximation, Taylor series approximation, and eigenvalues and eigenvectors, respectively, to compute the matrix exponential.

References [1] and [2] describe and compare many algorithms for computing a matrix exponential. The built-in method, `expm`, is essentially method 3 of [2].

Examples This example computes and compares the matrix exponential of `A` and the exponential of `A`.

```
A = [1       1       0
     0       0       2
     0       0      -1 ];

expm(A)
ans =
    2.7183   1.7183        1.0862
    0        1.0000        1.2642
    0             0        0.3679

exp(A)
ans =
    2.7183        2.7183        1.0000
    1.0000        1.0000        7.3891
    1.0000        1.0000        0.3679
```

Notice that the diagonal elements of the two results are equal. This would be true for any triangular matrix. But the off-diagonal elements, including those below the diagonal, are different.

See Also

`exp`, `funm`, `logm`, `sqrtm`

References

[1] Golub, G. H. and C. F. Van Loan, *Matrix Computation*, p. 384, Johns Hopkins University Press, 1983.

[2] Moler, C. B. and C. F. Van Loan, "Nineteen Dubious Ways to Compute the Exponential of a Matrix," *SIAM Review 20*, 1979, pp. 801-836.

Purpose Identity matrix

Syntax

```
Y = eye(n)
Y = eye(m,n)
Y = eye(size(A))
```

Description `Y = eye(n)` returns the `n`-by-`n` identity matrix.

`Y = eye(m,n)` or `eye([m n])` returns an `m`-by-`n` matrix with `1`'s on the diagonal and `0`'s elsewhere.

`Y = eye(size(A))` returns an identity matrix the same size as `A`.

Limitations The identity matrix is not defined for higher-dimensional arrays. The assignment `y = eye([2,3,4])` results in an error.

See Also `ones`, `rand`, `randn`, `zeros`

Purpose Easy to use contour plotter

Syntax

```
ezcontour(f)
ezcontour(f,domain)
ezcontour(...,n)
```

Description

`ezcontour(f)` plots the contour lines of *f(x,y)*, where `f` is a string that represents a mathematical function of two variables, such as *x* and *y*.

The function *f* is plotted over the default domain: $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$. MATLAB chooses the computational grid according to the amount of variation that occurs; if the function *f* is not defined (singular) for points on the grid, then these points are not plotted.

`ezcontour(f,domain)` plots *f(x,y)* over the specified `domain`. `domain` can be either a 4-by-1 vector [xmin, xmax, ymin, ymax] or a 2-by-1 vector [min, max] (where min < x < max, min < y < max).

If *f* is a function of the variables *u* and *v* (rather than *x* and *y*), then the domain endpoints umin, umax, vmin, and vmax are sorted alphabetically. Thus, `ezcontour('u^2 - v^3',[0,1],[3,6])` plots the contour lines for $u^2 - v^3$ over $0 < u < 1$, $3 < v < 6$.

`ezcontour(...,n)` plots *f* over the default domain using an `n`-by-`n` grid. The default value for `n` is 60.

`ezcontour` automatically adds a title and axis labels.

Remarks

Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezcontour`. For example, the MATLAB syntax for a contour plot of the expression,

```
sqrt(x.^2 + y.^2)
```

is written as:

```
ezcontour('sqrt(x^2 + y^2)')
```

That is, `x^2` is interpreted as `x.^2` in the string you pass to `ezcontour`.

Examples

The following mathematical expression defines a function of two variables, *x* and *y*.

$$f(x, y) = 3(1-x)^2 e^{-x^2-(y+1)^2} - 10\left(\frac{x}{5} - x^3 - y^5\right)e^{-x^2-y^2} - \frac{1}{3}e^{-(x+1)^2-y^2}$$

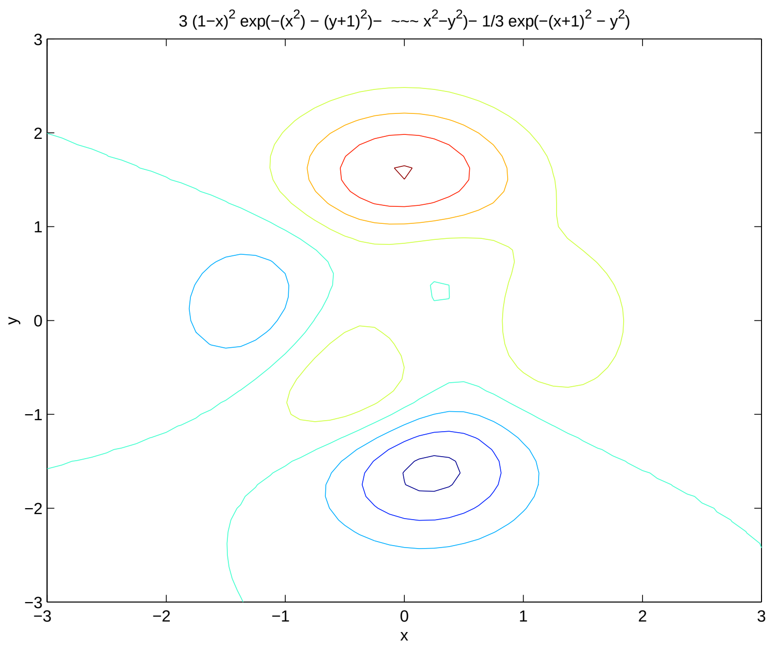
ezcontour requires a string argument that expresses this function using MATLAB syntax to represent exponents, natural logs, etc. This function is represented by the string:

```
f = ['3*(1–x)^2*exp(–(x^2)–(y+1)^2)',...
     '– 10*(x/5 – x^3 – y^5)*exp(-x^2–y^2)',...
     '- 1/3*exp(–(x+1)^2 – y^2)'];
```

For convenience, this string is written on three lines and concatenated into one string using square brackets.

Pass the string variable f to ezcontour along with a domain ranging from –3 to 3 and specify a computational grid of 49-by-49:

```
ezcontour(f,[-3,3],49)
```



In this particular case, the title is too long to fit at the top of the graph so MATLAB abbreviates the string.

See Also

`contour`, `ezcontourf`, `ezmesh`, `ezmeshc`, `ezplot`, `ezplot3`, `ezpolar`, `ezsurf`, `ezsurfc`

"Contour Plots" for related functions

Purpose Easy to use filled contour plotter

Syntax

```
ezcontourf(f)
ezcontourf(f,domain)
ezcontourf(...,n)
```

Description `ezcontourf(f)` plots the contour lines of *f(x,y)*, where `f` is a string that represents a mathematical function of two variables, such as *x* and *y*.

The function *f* is plotted over the default domain: $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$. MATLAB chooses the computational grid according to the amount of variation that occurs; if the function *f* is not defined (singular) for points on the grid, then these points are not plotted.

`ezcontourf(f,domain)` plots *f(x,y)* over the specified `domain`. `domain` can be either a 4-by-1 vector [xmin, xmax, ymin, ymax] or a 2-by-1 vector [min, max] (where, min < x < max, min < y < max).

If *f* is a function of the variables *u* and *v* (rather than *x* and *y*), then the domain endpoints umin, umax, vmin, and vmax are sorted alphabetically. Thus, `ezcontourf('u^2 - v^3',[0,1],[3,6])` plots the contour lines for $u^2 - v^3$ over $0 < u < 1$, $3 < v < 6$.

`ezcontourf(...,n)` plots *f* over the default domain using an `n`-by-`n` grid. The default value for `n` is 60.

`ezcontourf` automatically adds a title and axis labels.

Remarks Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezcontourf`. For example, the MATLAB syntax for a filled contour plot of the expression,

```
sqrt(x.^2 + y.^2);
```

is written as:

```
ezcontourf('sqrt(x^2 + y^2)')
```

That is, `x^2` is interpreted as `x.^2` in the string you pass to `ezcontourf`.

Examples The following mathematical expression defines a function of two variables, *x* and *y*.

$$f(x, y) = 3(1-x)^2 e^{-x^2-(y+1)^2} - 10\left(\frac{x}{5} - x^3 - y^5\right)e^{-x^2-y^2} - \frac{1}{3}e^{-(x+1)^2-y^2}$$

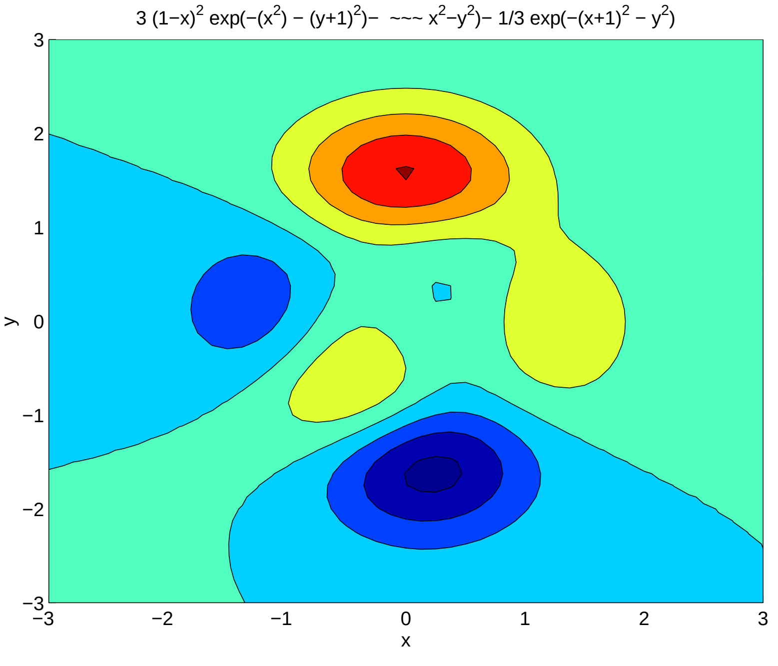
`ezcontourf` requires a string argument that expresses this function using MATLAB syntax to represent exponents, natural logs, etc. This function is represented by the string:

```
f = ['3*(1-x)^2*exp(-(x^2)-(y+1)^2)',...
     '- 10*(x/5 - x^3 - y^5)*exp(-x^2-y^2)',...
     '- 1/3*exp(-(x+1)^2 - y^2)'];
```

For convenience, this string is written on three lines and concatenated into one string using square brackets.

Pass the string variable `f` to `ezcontourf` along with a domain ranging from −3 to 3 and specify a grid of 49-by-49:

```
ezcontourf(f,[-3,3],49)
```



In this particular case, the title is too long to fit at the top of the graph so MATLAB abbreviates the string.

See Also

`contourf`, `ezcontour`, `ezmesh`, `ezmeshc`, `ezplot`, `ezplot3`, `ezpolar`, `ezsurf`, `ezsurfc`

“Contour Plots” for related functions

ezmesh

Purpose Easy to use 3-D mesh plotter

Syntax

```
ezmesh(f)
ezmesh(f,domain)
ezmesh(x,y,z)
ezmesh(x,y,z,[smin,smax,tmin,tmax]) or ezmesh(x,y,z,[min,max])
ezmesh(...,n)
ezmesh(...,'circ')
```

Description

`ezmesh(f)` creates a graph of $f(x,y)$, where `f` is a string that represents a mathematical function of two variables, such as x and y.

The function f is plotted over the default domain: $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$. MATLAB chooses the computational grid according to the amount of variation that occurs; if the function f is not defined (singular) for points on the grid, then these points are not plotted.

`ezmesh(f,domain)` plots f over the specified `domain`. `domain` can be either a 4-by-1 vector [xmin, xmax, ymin, ymax] or a 2-by-1 vector [min, max] (where, min < x < max, min < y < max).

If f is a function of the variables u and v (rather than x and y), then the domain endpoints umin, umax, vmin, and vmax are sorted alphabetically. Thus, `ezmesh('u^2 - v^3',[0,1],[3,6])` plots $u^2 - v^3$ over $0 < u < 1$, $3 < v < 6$.

`ezmesh(x,y,z)` plots the parametric surface $x = x(s,t)$, $y = y(s,t)$, and $z = z(s,t)$ over the square: $-2\pi < s < 2\pi$, $-2\pi < t < 2\pi$.

`ezmesh(x,y,z,[smin,smax,tmin,tmax])` or `ezmesh(x,y,z,[min,max])` plots the parametric surface using the specified domain.

`ezmesh(...,n)` plots f over the default domain using an `n`-by-`n` grid. The default value for `n` is 60.

`ezmesh(...,'circ')` plots f over a disk centered on the domain.

Remarks

Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezmesh`. For example, the MATLAB syntax for a mesh plot of the expression,

```
sqrt(x.^2 + y.^2);
```

is written as:

```
ezmesh('sqrt(x^2 + y^2)')
```

That is, `x^2` is interpreted as `x.^2` in the string you pass to `ezmesh`.

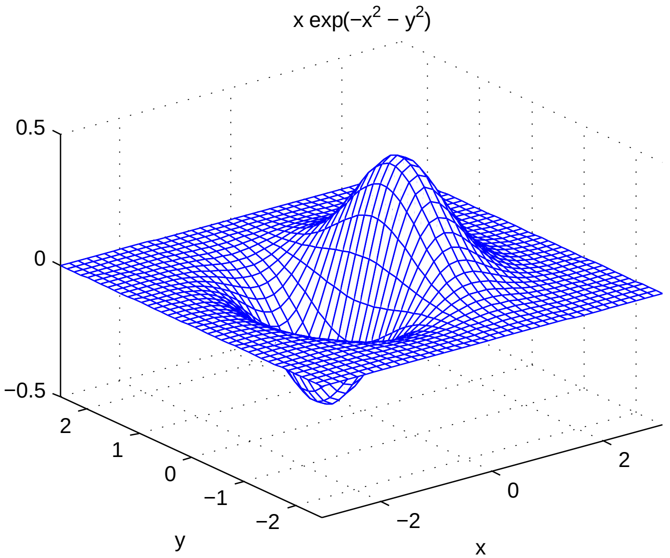
Examples

This example visualizes the function,

$$f(x, y) = xe^{-x^2 - y^2}$$

with a mesh plot drawn on a 40-by-40 grid. The mesh lines are set to a uniform blue color by setting the colormap to a single color:

```
ezmesh('x*exp(-x^2-y^2)',40)
colormap([0 0 1])
```



See Also

`ezmeshc`, `mesh`

"Function Plots" for related functions

Purpose

Easy to use combination mesh/contour plotter

Syntax

```
ezmeshc(f)
ezmeshc(f,domain)
ezmeshc(x,y,z)
ezmeshc(x,y,z,[smin,smax,tmin,tmax]) or ezmeshc(x,y,z,[min,max])
ezmeshc(...,n)
ezmeshc(...,'circ')
```

Description

`ezmeshc(f)` creates a graph of *f(x,y)*, where *f* is a string that represents a mathematical function of two variables, such as *x* and y.

The function *f* is plotted over the default domain: $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$. MATLAB chooses the computational grid according to the amount of variation that occurs; if the function *f* is not defined (singular) for points on the grid, then these points are not plotted.

`ezmeshc(f,domain)` plots *f* over the specified `domain`. `domain` can be either a 4-by-1 vector [xmin, xmax, ymin, ymax] or a 2-by-1 vector [min, max] (where, min < *x* < max, min < *y* < max).

If *f* is a function of the variables *u* and *v* (rather than *x* and *y*), then the domain endpoints umin, umax, vmin, and vmax are sorted alphabetically. Thus, `ezmeshc('u^2 - v^3',[0,1],[3,6])` plots $u^2 - v^3$ over $0 < u < 1$, $3 < v < 6$.

`ezmeshc(x,y,z)` plots the parametric surface $x = x(s,t)$, $y = y(s,t)$, and $z = z(s,t)$ over the square: $-2\pi < s < 2\pi$, $-2\pi < t < 2\pi$.

`ezmeshc(x,y,z,[smin,smax,tmin,tmax])` or `ezmeshc(x,y,z,[min,max])` plots the parametric surface using the specified domain.

`ezmeshc(...,n)` plots *f* over the default domain using an `n`-by-`n` grid. The default value for `n` is 60.

`ezmeshc(...,'circ')` plots *f* over a disk centered on the domain.

Remarks

Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezmeshc`. For example, the MATLAB syntax for a mesh/contour plot of the expression,

```
sqrt(x.^2 + y.^2);
```

is written as:

```
ezmeshc('sqrt(x^2 + y^2)')
```

That is, `x^2` is interpreted as `x.^2` in the string you pass to `ezmeshc`.

Examples

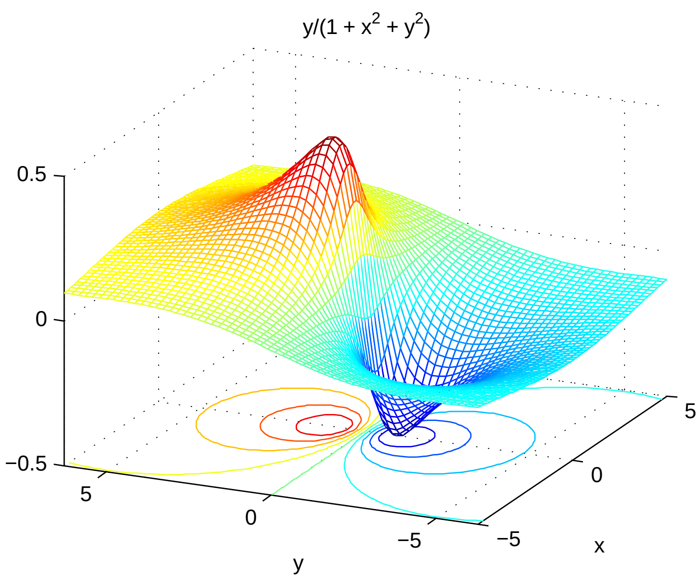
Create a mesh/contour graph of the expression,

$$f(x, y) = \frac{y}{1 + x^2 + y^2}$$

over the domain -5 < x < 5, -2*pi < y < 2*pi:

```
ezmeshc('y/(1 + x^2 + y^2)',[−5,5,−2*pi,2*pi])
```

Use the mouse to rotate the axes to better observe the contour lines (this picture uses a view of azimuth = -65.5 and elevation = 26).



See Also

`ezmesh`, `ezsurfc`, `meshc`

“Function Plots” for related functions

ezplot

Purpose Easy to use function plotter

Syntax

```
ezplot(f)
ezplot(f,[min,max])
ezplot(f,[xmin,xmax,ymin,ymax])
ezplot(x,y)
ezplot(x,y,[tmin,tmax])
ezplot(...,figure)
```

Description

`ezplot(f)` plots the expression $f = f(x)$ over the default domain: $-2\pi < x < 2\pi$.

`ezplot(f,[min,max])` plots $f = f(x)$ over the domain: `min` $< x <$ `max`.

For implicitly defined functions, $f = f(x,y)$:

`ezplot(f)` plots $f(x,y) = 0$ over the default domain $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$.

`ezplot(f,[xmin,xmax,ymin,ymax])` plots $f(x,y) = 0$ over `xmin` $< x <$ `xmax` and `ymin` $< y <$ `ymax`.

`ezplot(f,[min,max])`plots $f(x,y) = 0$ over `min` $< x <$ `max` and `min` $< y <$ `max`.

If f is a function of the variables u and v (rather than x and y), then the domain endpoints umin, umax, vmin, and vmax are sorted alphabetically. Thus, `ezplot('u^2 - v^2 - 1',[-3,2,-2,3])` plots $u^2 - v^2 - 1 = 0$ over $-3 < u < 2$, $-2 < v < 3$.

`ezplot(x,y)` plots the parametrically defined planar curve $x = x(t)$ and $y = y(t)$ over the default domain $0 < t < 2\pi$.

`ezplot(x,y,[tmin,tmax])` plots $x = x(t)$ and $y = y(t)$ over `tmin` $< t <$ `tmax`.

`ezplot(...,figure)` plots the given function over the specified domain in the figure window identified by the handle `figure`.

Remarks

Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezplot`. For example, the MATLAB syntax for a plot of the expression,

```
x.^2 - y.^2
```

which represents an implicitly defined function, is written as:

```
ezplot('x^2 - y^2')
```

That is, `x^2` is interpreted as `x.^2` in the string you pass to `ezplot`.

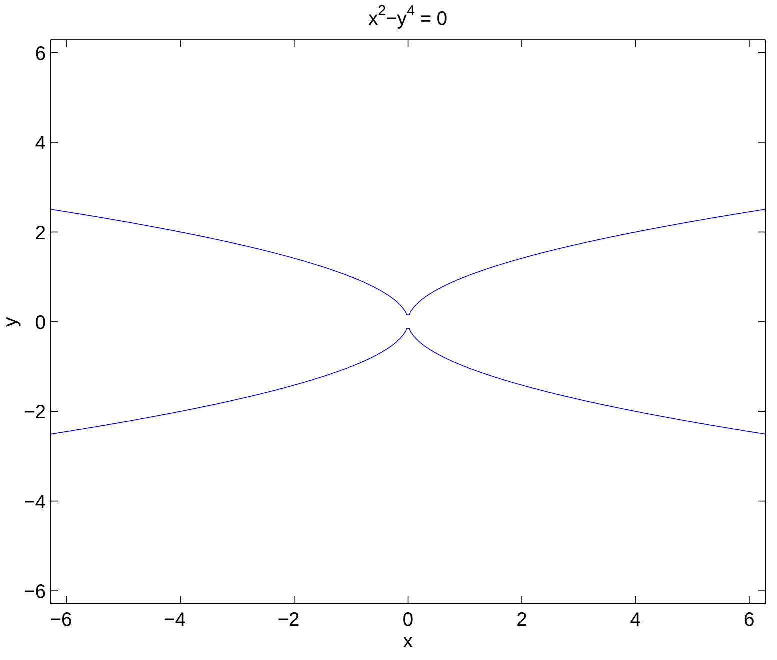
Examples

This example plots the implicitly defined function,

$$x^2 - y^4 = 0$$

over the domain [-2π, 2π]:

```
ezplot('x^2-y^4')
```



See Also

`ezplot3`, `ezpolar`, `plot`

"Function Plots" for related functions

ezplot3

Purpose

Easy to use 3-D parametric curve plotter

Syntax

```
ezplot3(x,y,z)
ezplot3(x,y,z,[tmin,tmax])
ezplot3(...,'animate')
```

Description

`ezplot3(x,y,z)` plots the spatial curve $x = x(t)$, $y = y(t)$, and $z = z(t)$ over the default domain $0 < t < 2\pi$.

`ezplot3(x,y,z,[tmin,tmax])` plots the curve $x = x(t)$, $y = y(t)$, and $z = z(t)$ over the domain `tmin` < t < `tmax`.

`ezplot3(...,'animate')` produces an animated trace of the spatial curve.

Remarks

Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezplot3`. For example, the MATLAB syntax for a plot of the expression,

```
x = s./2, y = 2.*s, z = s.^2;
```

which represents a parametric function, is written as:

```
ezplot3('s/2','2*s','s^2')
```

That is, `s/2` is interpreted as `s./2` in the string you pass to `ezplot3`.

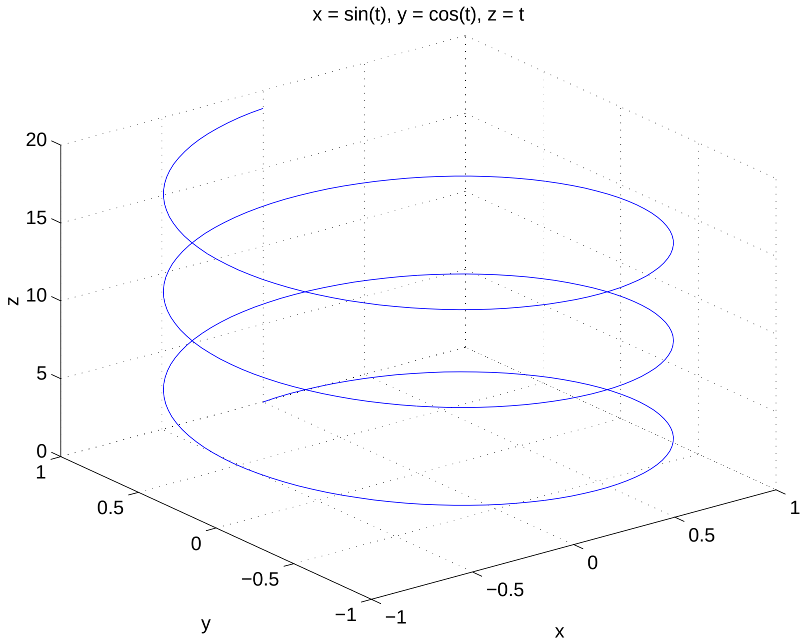
Examples

This example plots the parametric curve,

$$x = \sin t, \qquad y = \cos t, \qquad z = t$$

over the domain $[0,6\pi]$:

```
ezplot3('sin(t)','cos(t)','t',[0,6*pi])
```



See Also

`ezplot`, `ezpolar`, `plot3`

"Function Plots" for related functions

ezpolar

Purpose Easy to use polar coordinate plotter

Syntax

```
ezpolar(f)
ezpolar(f,[a,b])
```

Description `ezpolar(f)` plots the polar curve *rho* = *f(theta)* over the default domain 0 < theta < 2π.

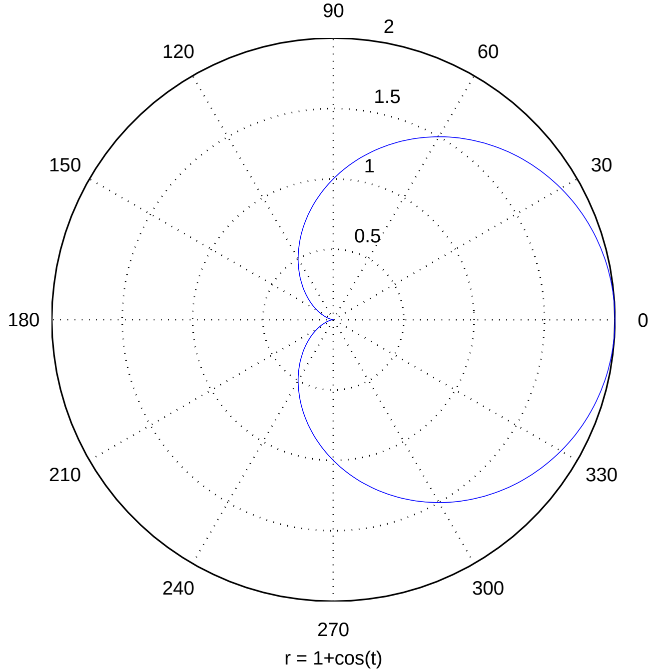
`ezpolar(f,[a,b])` plots *f* for `a` < *theta* < `b`.

Examples This example creates a polar plot of the function,

1 + cos(t)

over the domain [0, 2π]:

```
ezpolar('1+cos(t)')
```



See Also `ezplot`, `ezplot3`, `plot`, `plot3`, `polar`

“Function Plots” for related functions

Purpose Easy to use 3-D colored surface plotter

Syntax

```
ezsurf(f)
ezsurf(f,domain)
ezsurf(x,y,z)
ezsurf(x,y,z,[smin,smax,tmin,tmax]) or ezsurf(x,y,z,[min,max])
ezsurf(...,n)
ezsurf(...,'circ')
```

Description

`ezsurf(f)` creates a graph of $f(x,y)$, where `f` is a string that represents a mathematical function of two variables, such as x and y.

The function f is plotted over the default domain: $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$. MATLAB chooses the computational grid according to the amount of variation that occurs; if the function f is not defined (singular) for points on the grid, then these points are not plotted.

`ezsurf(f,domain)` plots f over the specified `domain`. `domain` can be either a 4-by-1 vector [xmin, xmax, ymin, ymax] or a 2-by-1 vector [min, max] (where, min < x < max, min < y < max).

If f is a function of the variables u and v (rather than x and y), then the domain endpoints umin, umax, vmin, and vmax are sorted alphabetically. Thus, `ezsurf('u^2 - v^3',[0,1],[3,6])` plots $u^2 - v^3$ over $0 < u < 1$, $3 < v < 6$.

`ezsurf(x,y,z)` plots the parametric surface $x = x(s,t)$, $y = y(s,t)$, and $z = z(s,t)$ over the square: $-2\pi < s < 2\pi$, $-2\pi < t < 2\pi$.

`ezsurf(x,y,z,[smin,smax,tmin,tmax])` or `ezsurf(x,y,z,[min,max])` plots the parametric surface using the specified domain.

`ezsurf(...,n)` plots f over the default domain using an `n`-by-`n` grid. The default value for `n` is 60.

`ezsurf(...,'circ')` plots f over a disk centered on the domain.

Remarks

Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezsurf`. For example, the MATLAB syntax for a surface plot of the expression,

```
sqrt(x.^2 + y.^2);
```

is written as:

```
ezsurf('sqrt(x^2 + y^2)')
```

That is, `x^2` is interpreted as `x.^2` in the string you pass to `ezsurf`.

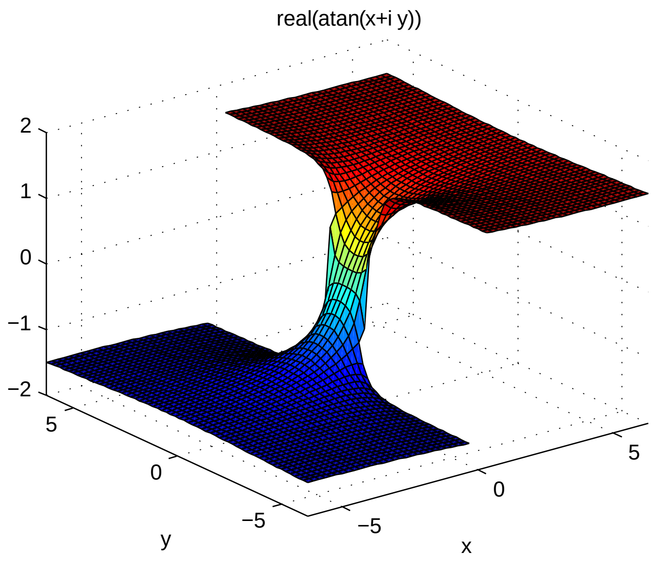
Examples

`ezsurf` does not graph points where the mathematical function is not defined (these data points are set to `NaN`s, which MATLAB does not plot). This example illustrates this filtering of singularities/discontinuous points by graphing the function,

$$f(x, y) = real(atan(x + iy))$$

over the default domain $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$:

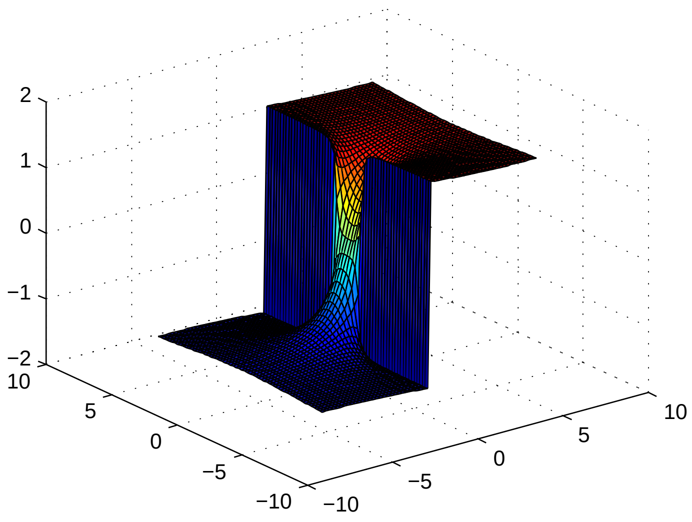
```
ezsurf('real(atan(x+i*y))')
```



Using `surf` to plot the same data produces a graph without filtering of discontinuities (as well as requiring more steps):

```
[x,y] = meshgrid(linspace(-2*pi,2*pi,60));
z = real(atan(x+i.*y));
```

```
surf(x,y,z)
```



Note also that `ezsurf` creates graphs that have axis labels, a title, and extend to the axis limits.

See Also

`ezmesh`, `ezsurfc`, `surf`

“Function Plots” for related functions

Purpose Easy to use combination surface/contour plotter

Syntax

```
ezsurfc(f)
ezsurfc(f,domain)
ezsurfc(x,y,z)
ezsurfc(x,y,z,[smin,smax,tmin,tmax]) or ezsurfc(x,y,z,[min,max])
ezsurfc(...,n)
ezsurfc(...,'circ')
```

Description

`ezsurfc(f)` creates a graph of *f(x,y)*, where `f` is a string that represents a mathematical function of two variables, such as *x* and *y*.

The function *f* is plotted over the default domain: $-2\pi < x < 2\pi$, $-2\pi < y < 2\pi$. MATLAB chooses the computational grid according to the amount of variation that occurs; if the function *f* is not defined (singular) for points on the grid, then these points are not plotted.

`ezsurfc(f,domain)` plots *f* over the specified `domain`. `domain` can be either a 4-by-1 vector [xmin, xmax, ymin, ymax] or a 2-by-1 vector [min, max] (where, min < *x* < max, min < *y* < max).

If *f* is a function of the variables *u* and *v* (rather than *x* and *y*), then the domain endpoints umin, umax, vmin, and vmax are sorted alphabetically. Thus, `ezsurfc('u^2 - v^3',[0,1],[3,6])` plots $u^2 - v^3$ over $0 < u < 1$, $3 < v < 6$.

`ezsurfc(x,y,z)` plots the parametric surface $x = x(s,t)$, $y = y(s,t)$, and $z = z(s,t)$ over the square: $-2\pi < s < 2\pi$, $-2\pi < t < 2\pi$.

`ezsurfc(x,y,z,[smin,smax,tmin,tmax])` or `ezsurfc(x,y,z,[min,max])` plots the parametric surface using the specified domain.

`ezsurfc(...,n)` plots *f* over the default domain using an `n`-by-`n` grid. The default value for `n` is 60.

`ezsurfc(...,'circ')` plots *f* over a disk centered on the domain.

Remarks

Array multiplication, division, and exponentiation are always implied in the expression you pass to `ezsurfc`. For example, the MATLAB syntax for a surface/contour plot of the experssion,

```
sqrt(x.^2 + y.^2);
```

is written as:

```
ezsurfc('sqrt(x^2 + y^2)')
```

That is, `x^2` is interpreted as `x.^2` in the string you pass to `ezsurfc`.

Examples

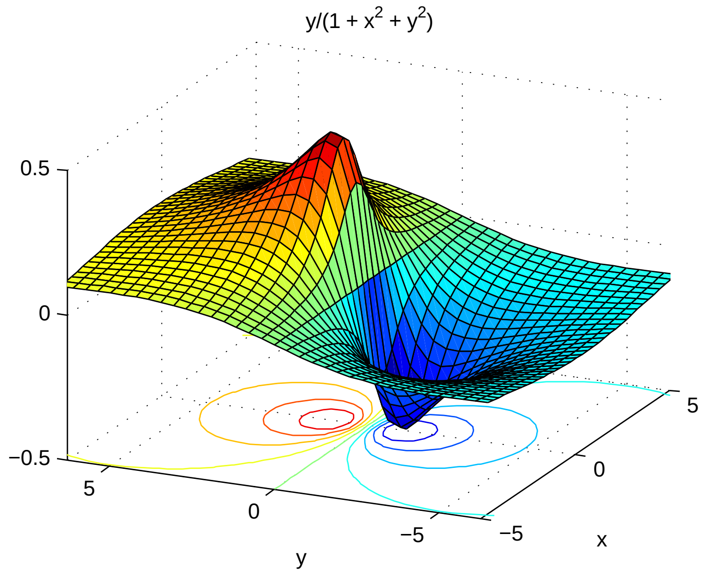
Create a surface/contour plot of the expression,

$$f(x, y) = \frac{y}{1 + x^2 + y^2}$$

over the domain -5 < x < 5, -2*pi < y < 2*pi, with a computational grid of size 35-by-35:

```
ezsurfc('y/(1 + x^2 + y^2)',[−5,5,−2*pi,2*pi],35)
```

Use the mouse to rotate the axes to better observe the contour lines (this picture uses a view of azimuth = -65.5 and elevation = 26)



See Also

`ezmesh`, `ezmeshc`, `ezsurf`, `surfc`

“Function Plots” for related functions

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