

IMSL®
C# Numerical Library

Chart Programmer's User Guide

VERSION 6.5

THIS RELEASE IS DEDICATED TO
DR. JOHN F. BROPHY
1953-2008

OUR MENTOR AND FRIEND
WHOSE UNSELFISH EFFORTS WILL HAVE
A LASTING IMPACT ON THE IMSL PRODUCT LINE.

WE WERE BLESSED TO HAVE HAD JOHN AS A MEMBER OF OUR TEAM FOR 25 YEARS.

THE VISUAL NUMERICS PRODUCT DEVELOPMENT TEAM



IMSL[®] Numerical Library V.6.)
Chart Programmer's User Guide

Trusted for Over 35 Years



CORPORATE HEADQUARTERS

Rogue Wave Software
5500 Flatiron Parkway Suite 200
Boulder, CO 80301 USA

IMSL Libraries Contact Information

USA Toll Free: 800.222.4675
T: 713.784.3131 F: 713.781.9260
Email: info@vni.com
Web site: www.vni.com

Worldwide Offices

USA • UK • France • Germany • Japan
For contact information, please visit
www.vni.com/contact/worldwideoffices.php

© 1970-2016 Visual Numerics, Inc. All rights reserved.

Visual Numerics, IMSL and PV-WAVE are registered trademarks of Visual Numerics, Inc. in the U.S. and other countries. JMSL, JWAVE, TS-WAVE, PyIMSL and Knowledge in Motion are trademarks of Visual Numerics, Inc. All other company, product or brand names are the property of their respective owners.

IMPORTANT NOTICE: Information contained in this documentation is subject to change without notice. Use of this document is subject to the terms and conditions of a Visual Numerics Software License Agreement, including, without limitation, the Limited Warranty and Limitation of Liability. If you do not accept the terms of the license agreement, you may not use this documentation and should promptly return the product for a full refund. This documentation may not be copied or distributed in any form without the express written consent of Visual Numerics.



Embeddable mathematical and statistical algorithms available for C, C#.NET, Java™, Fortran and Python applications

Table of Contents

Preface	1
What's in this Manual	1
Contacting Visual Numerics Support.....	1
Chapter 1: Introduction – Chart 2D	4
Chart 2D.....	4
Overview.....	4
Implicitly Created Nodes	6
Adding a Chart to an Application	9
Chapter 2: Charting 2D Types	12
Chart Types	12
Scatter Plot.....	12
Simple Scatter Plot	13
Complex Scatter Plot	14
Line Plot.....	15
Simple Line Plot	15
Mixed Line and Marker Plot.....	17
Area Plot	18
Simple Area Plot.....	18
Painted Area Example	19
Attribute Reference.....	21
Function Plot.....	21
Example	21
Histogram Example	23
Spline Chart	23
Log and SemiLog Plot	24
SemiLog Plot	24
Log-Log Plot.....	26
Error Bar Plot.....	27
Vertical Error Bars.....	27
Horizontal Error Bars	29
Mixed Error Bars	30
High-Low-Close Plot	32
Example	32
Candlestick Chart.....	34
Example	35
Pie Chart.....	37
Example	38
Box Plot	40
Example	40

Bar Chart	42
Simple Bar Chart	42
Attribute BarGap.....	44
Attribute BarWidth	44
Grouped Bar Chart	44
Stacked Grouped Bar Chart.....	45
Legend.....	47
Contour Chart.....	48
Example	49
Heatmap	50
Example	51
Treemap	52
Example	52
Histogram.....	54
Example	54
Polar Plot.....	56
Example	57
Dendrogram Chart.....	59
Example	59

Chapter 3: Quality Control and Improvement Charts 64

Introduction	64
Shewhart Charts	64
Variable Control Charts:	66
Attribute Control Charts:.....	67
Other Control Charts	67
Process Improvement Charts.....	67
ShewhartControlChart and ControlLimit	67
XbarS and SChart.....	70
XbarS Example	70
SChart Example	72
XbarSCombo Example	74
XbarSUnequal Example.....	76
XbarR and RChart.....	78
XbarR Example.....	79
XbarRCombo Example	81
XmR.....	82
XmR Example.....	83
PChart	84
PChart Example	84
PChartUnequal Example.....	86
NpChart.....	87
NpChart Example	88
CChart.....	89
CChart Example.....	89
CChartOmit Example.....	91
UChart.....	92
UChart Example	93
UChartUnequal Example	94
EWMA.....	96
EWMA Example.....	96

CuSum	98
CuSum Example	98
CuSumStatus	100
CuSumStatus Example	100
Pareto Chart	102
ParetoChart Example	102
Cumulative Probability	104
CumulativeProbability Example	104

Chapter 4: Drawing Elements 108

Chart 2D Drawing Elements	108
Line Attributes	108
Attribute LineColor	108
Attribute LineWidth.....	108
Attribute LineDashPattern	109
Samples.....	109
Marker Attributes.....	109
Attribute MarkerType	109
Attribute MarkerColor	110
Attribute MarkerSize	110
Attribute MarkerThickness	111
Attribute MarkerDashPattern.....	111
Samples.....	111
Fill Area Attributes	111
FillOutlineType.....	111
FillOutlineColor.....	112
FillType	112
FillColor.....	112
Gradient	112
FillPaint.....	113
Text Attributes	114
Attribute Font	114
Attribute FontName	114
Attribute FontSize.....	115
Attribute FontStyle	115
Attribute TextAngle.....	115
Attribute TextColor	115
Attribute TextFormat	115
Attribute TextFormatProvider	115
Attribute Title	115
Samples.....	116
Labels.....	117
Attribute LabelType.....	117
Data Point Labeling Example	117
Annotation	119
AxisXY	121
Axis Layout	122
Transform	124

Autoscale	125
Axis Label	126
Axis Title.....	126
Axis Unit	129
Major and Minor Tick Marks.....	131
Grid	133
Custom Transform	135
Multiple Axes.....	138
Cross Example	140
Background	142
Solid Color Background	142
Gradient Color Background.....	144
Pattern Background.....	145
Legend.....	146
Simple Legend Example	146
Legend Example	148
Colormaps	150
Tool Tips.....	151
Example	151
Chapter 5: Actions	154
IMSL C# Numerical Libraries	154
Picking	154
Example	154
Zoom.....	156
Example	156
Printing.....	161
Printing from FrameChart.....	161
Printable Interface.....	162
Appendix A: Web Server Application	164
Appendix B: Writing a Chart as a Bitmap Image	166
Using the ImageIO class	166
Appendix C: Picture-in-Picture	170
Index	175

Preface

What's in this Manual

The IMSL C# Numerical Library Chart Programmer's Guide explains how to create 2D charting with the IMSL C# Numerical Library.

Chart 2D contains the following sections:

Provides an overview of the scope of the most commonly used 2D charting classes..... [Introduction - Chart2D](#)
Describes the IMSL C# Library 2D Charts. [Charting 2D Types](#)
Quality Control Charts. ... [Quality Control and Improvement Charts](#)
Discusses the IMSL C# Library chart drawing elements..... [2D Drawing Elements](#)
Discusses actions available in 2D charting. [Actions](#)

Appendices:

Describes IMSL C# and web servlets..... [Web Server Application](#)
Describes the ways to save bitmap images..... [Writing a Chart as a Bitmap Image File](#)
Describes the picture-in-picture effects. [Picture-in-Picture](#)

Contacting Visual Numerics Support

Users within support warranty may contact Visual Numerics, Inc. regarding the use of the IMSL C# Numerical Library. Visual Numerics, Inc. can consult on the following topics:

- Clarity of documentation
- Possible Visual Numerics-related programming problems
- Choice of IMSL Numerical Libraries functions or procedures for a particular problem

Not included in these topics are mathematical/statistical consulting and debugging of your program.

Refer to the following for the IMSL Libraries Technical Support:

- <http://www.vni.com/tech/imsl/index.php>

The following describes the procedure for consultation with Visual Numerics:

- Include your Visual Numerics license number
- Include the product name and version number: IMSL C# Numerical Library Version 6.5
- Include compiler and operating system version numbers
- Include the name of the class for which assistance is needed and a description of the problem

Chapter 1: Introduction – Chart 2D

Chart 2D

The IMSL C# Numerical Library Chart Programmer User's Guide is an overview and discussion of the IMSL C# Numerical Library charting package. It is intended to be used in conjunction with the online [Reference Manual](#).

This guide is both an introductory tutorial on the charting package and a “cookbook” for creating common chart types. The Reference Manual contains the complete details of the classes.

NOTE: Charts in the printed version of this manual appear in black and white. If you are reading this manual in print and wish to see the charts in color, please open the Acrobat Reader file: /manual/WordDocuments/chartpg.pdf.

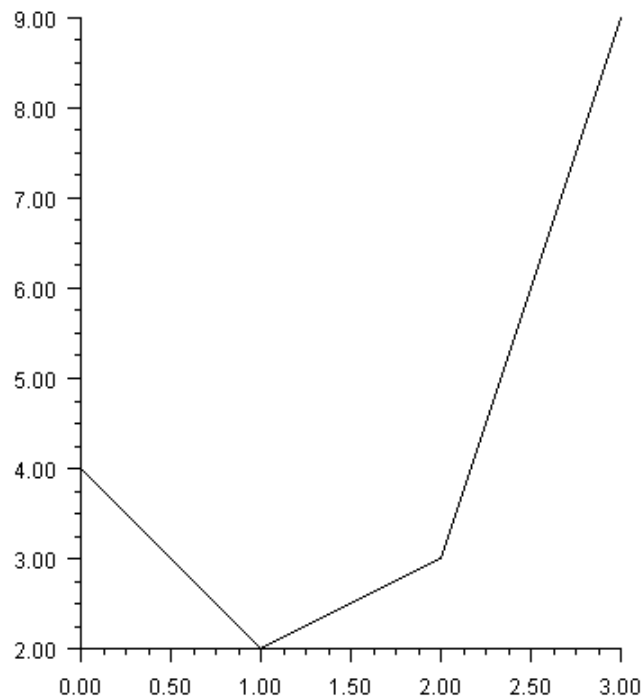
If you do not have Acrobat Reader installed on your machine, you can download it for free at: <http://get.adobe.com/reader/>.

Or you may also view the Guide in color from our Web site at: <http://www.vni.com/products/imsl/documentation/index.php#imslcnumlib65> .

Overview

The IMSL C# Numerical Library chart package is designed to allow the creation of highly customizable charts using any .NET language. An IMSL C# Numerical Library chart is created by assembling [ChartNodes](#) into a tree. This chart tree is then rendered to the screen or printer.

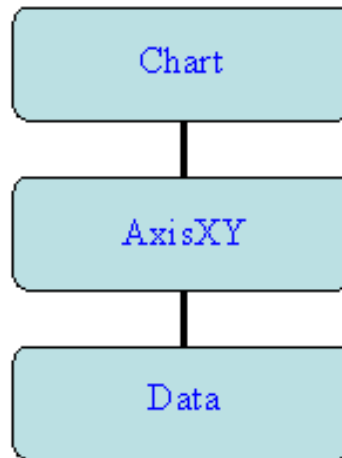
The following class is a simple example of the use of the IMSL C# Numerical Library chart package. The chart is displayed in a [Windows.Forms.Form](#). The code to create the chart is all in the constructor. The IMSL C# Numerical Library class [FrameChart](#) extends the [.NET](#) class `Form` and creates a [Chart](#) object.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
  
public class Intro1 : FrameChart {  
  
    public Intro1() {  
        Chart chart = this.Chart;  
        AxisXY axis = new AxisXY(chart);  
        double[] y = new double[] {4, 2, 3, 9};  
        new Data(axis, y);  
    }  
  
    public static void Main(string[] argv) {  
        System.Windows.Forms.Application.Run(new Intro1());  
    }  
}
```

The above example created and assembled three nodes into the following tree. The root [Chart](#) node is created by the [FrameChart](#) class.



The general pattern of the [ChartNode](#) class, and classes derived from it, is to have constructors whose first argument is the parent [ChartNode](#) of the [ChartNode](#) being created.

The root node of the tree is always a [Chart](#) object. It is usually constructed within [FrameChart](#) or [PanelChart](#), which handles the repainting of the chart within Windows Forms. If a [Chart](#) object is explicitly created, and used within a Windows form, then its [Paint\(Graphics\)](#) method must be called from the container's [Paint\(Graphics\)](#) method.

Chart nodes can contain attributes, such as [FillColor](#) and [LineWidth](#). Attributes are inherited via the chart tree. For example, when a [Data](#) node is being painted, its [LineWidth](#) attribute determines the thickness of the line. If this attribute is set in the data node being drawn, that is the value used. If it is not set, then its parent node (an [AxisXY](#) node in the above example) is queried. If it is not set there, then *its* parent is queried. This continues until the root node is reached after which a default value is used. Note that this inheritance is not the same as C# class inheritance.

Attributes are set using `axis.LineWidth = value` or `SetViewport(double[])` and retrieved using `axis.LineWidth` or `GetViewport()`.

Implicitly Created Nodes

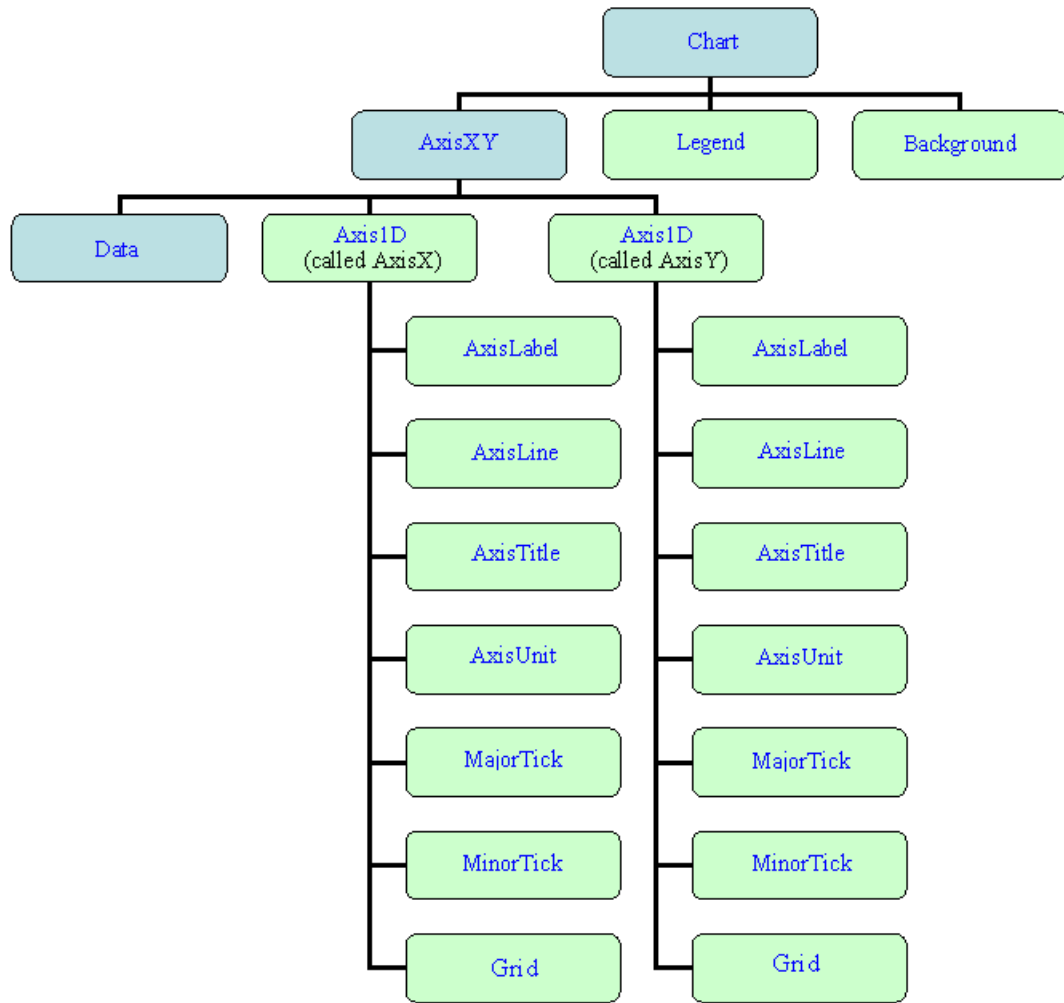
Some chart nodes automatically create additional nodes, as their children, when they are created. These nodes can be accessed by `Get` methods or properties. For example, the code

```
chart.Background.FillColor = System.Drawing.Color.Green;
```

changes the background color.

The [Background](#) property retrieves the [Background](#) node from the chart object and the [FillColor](#) property sets the [Background](#) object's [FillColor](#) attribute to [Color.Green](#).

In the following diagram, the nodes automatically created are shown in light green (to view in color see the online documentation).

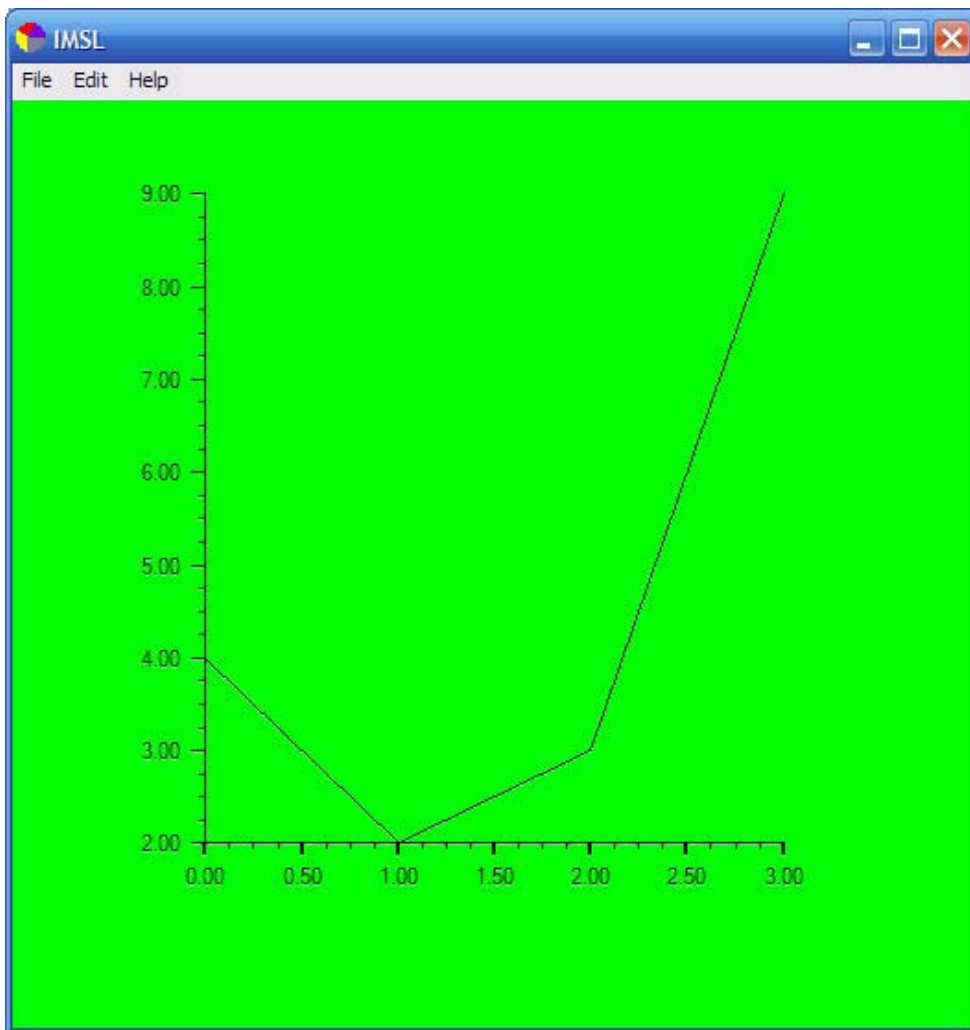


Method calls and property references can be chained together. For example, the following sets the thickness of the major tick marks on the *x*-axis:

```
axis.AxisX.MajorTick.LineWidth = 2.0;
```

where *axis* is an [AxisXY](#) object.

A customized version of the above chart can be obtained by changing its constructor as in the following:



[\(Download Code\)](#)

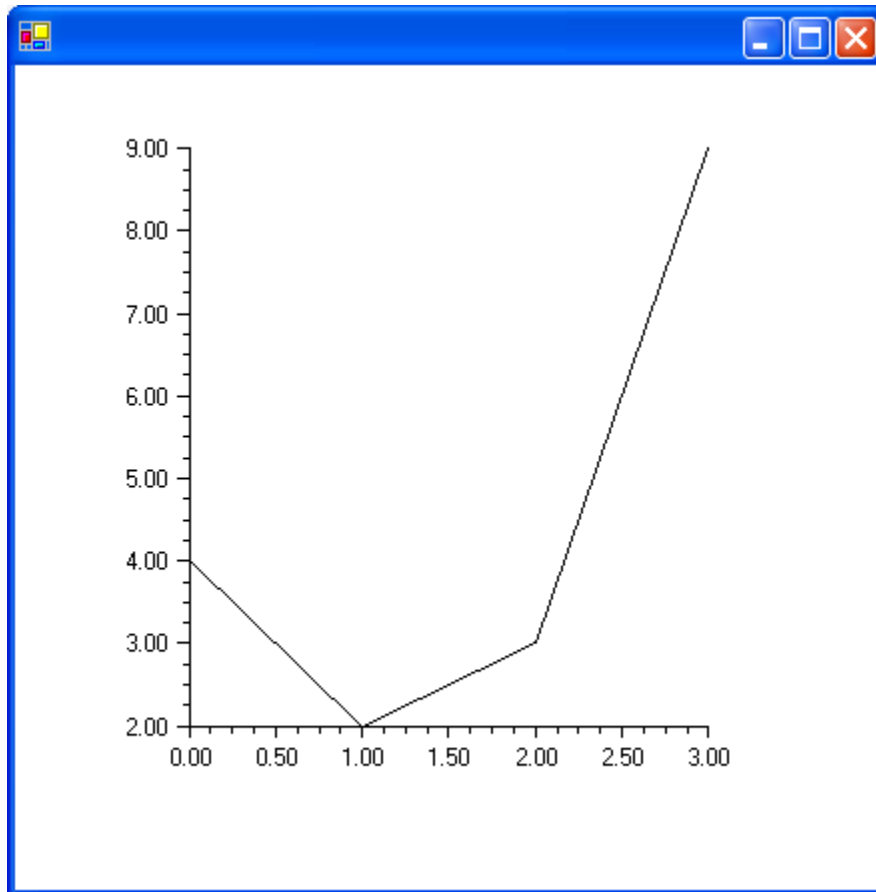
```
using Imsl.Chart2D;  
  
public class Intro2 : FrameChart {  
  
    public Intro2() {  
        Chart chart = this.Chart;  
        AxisXY axis = new AxisXY(chart);  
        double[] y = new double[] {4, 2, 3, 9};  
        new Data(axis, y);  
        chart.Background.FillColor = System.Drawing.Color.Lime;  
        axis.AxisX.MajorTick.LineWidth = 2.0;  
    }  
}
```



```
}  
  
public static void Main(string[] argv) {  
    System.Windows.Forms.Application.Run(new Intro2());  
}  
}
```

Adding a Chart to an Application

For simplicity, most of the examples in this manual use the [FrameChart](#) class. `FrameChart` is useful for quickly building an application that is a chart. The class [PanelChart](#) is used to build a chart into a larger application. It extends .NET's [Windows.Forms.Panel](#) class and can be used wherever a `Panel` can be used. The following code shows a `PanelChart` being created, added to a [Form](#), which contains the `Chart` hierarchy. (The generated chart is very similar to that shown at the beginning of this chapter.)



[\(Download Code\)](#)

```
using Imsl.Chart2D;
```

```
public class SamplePanel : System.Windows.Forms.Form
{
    private PanelChart panelChart;

    public SamplePanel()
    {
        panelChart = new PanelChart();
        panelChart.Dock = System.Windows.Forms.DockStyle.Fill;
        this.Controls.Add(panelChart);

        Chart chart = panelChart.Chart;
        AxisXY axis = new AxisXY(chart);
        double[] y = new double[] {4, 2, 3, 9};
        new Data(axis, y);
    }

    public static void Main(string[] argv)
    {
        System.Windows.Forms.Application.Run(new SamplePanel());
    }
}
```


Chapter 2: Charting 2D Types

Chart Types

This chapter describes these IMSL C# Numerical Library charting types:

- [“Scatter Plot”](#) on page 12
- [“Line Plot”](#) on page 15
- [“Area Plot”](#) on page 18
- [“Function Plot”](#) on page 21
- [“Log and SemiLog Plot”](#) on page 24
- [“Error Bar Plot”](#) on page 27
- [“High-Low-Close Plot”](#) on page 32
- [“Candlestick Chart”](#) on page 34
- [“Pie Chart”](#) on page 37
- [“Box Plot”](#) on page 40
- [“Bar Chart”](#) on page 42
- [“Contour Chart”](#) on page 48
- [“Heatmap”](#) on page 50
- [“Treemap”](#) on page 52
- [“Histogram”](#) on page 54
- [“Polar Plot”](#) on page 56
- [“Dendrogram Chart”](#) on page 59

Scatter Plot

This section describes the construction of scatter plots. The markers can be formatted using the [Marker Attributes](#).

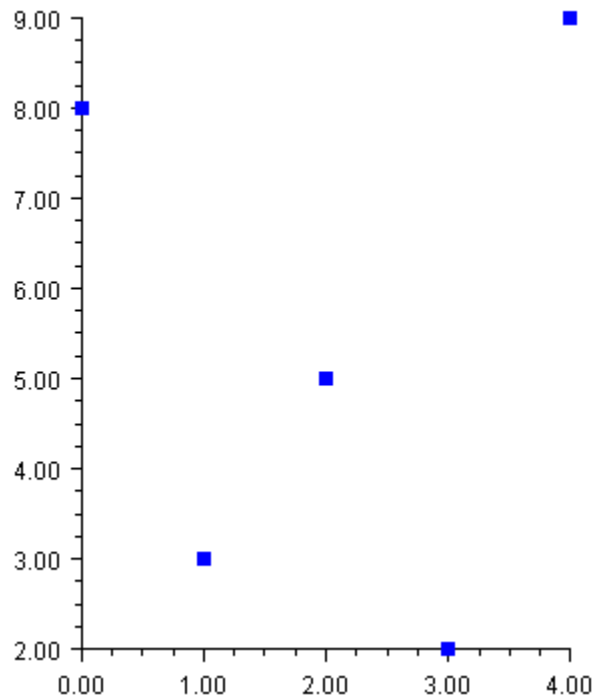
It is also possible to mix lines and markers (see [“Mixed Line and Marker Plot”](#) on page 17).

Simple Scatter Plot

The [FrameChart](#) class is used to create a frame containing a [Chart](#) node. The [Chart](#) node is the root of the tree to which an [AxisXY](#) node is added. A [Data](#) node is then created as the child of the axis node. The [Data](#) node is created using an array of *y*-values. The *x*-values default to 0, 1,

The `DataType` attribute is set to [DATA_TYPE_MARKER](#) to make this a scatter plot.

The look of the markers is controlled by the marker attributes. In this example the [MarkerType](#) attribute is set to [MARKER_TYPE_FILLED_SQUARE](#). The [MarkerColor](#) attribute is set to blue (to view plot in color see online documentation).



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using System.Drawing;  
  
public class SampleSimpleScatter : FrameChart {  
  
    public SampleSimpleScatter() {  
        Chart chart = this.Chart;  
        AxisXY axis = new AxisXY(chart);  
  
        double[] y = new double[] {8, 3, 5, 2, 9};  
    }  
}
```

```

    Data data1 = new Data(axis, y);
    data1.DataType = Data.DATA_TYPE_MARKER;
    data1.MarkerType = Data.MARKER_TYPE_FILLED_SQUARE;
    data1.MarkerColor = Color.Blue;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleSimpleScatter());
}
}

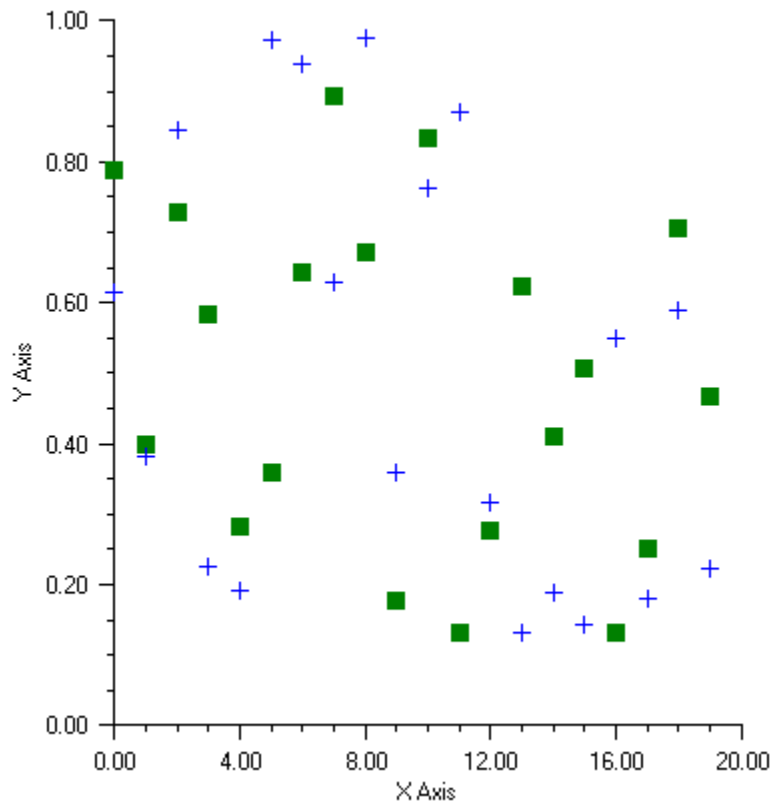
```

Complex Scatter Plot

This example shows a scatter plot with two data sets. The [Data](#) nodes are created using random y-values generated by [Random](#). The x-values default to 0, 1,

The axes are labeled by setting the [AxisTitle](#) attribute for the x and y axes.

The `DataType` attribute is set in the axis node (`axis.DataType = Data.DATA_TYPE_MARKER;`). The axis node does not itself use this attribute, but from there it is inherited by the child `Data` nodes.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;
using Imsl.Stat;

public class SampleScatter : FrameChart {

    public SampleScatter() {
        Random r = new Random(123457);

        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        axis.AxisX.AxisTitle.SetTitle("X Axis");
        axis.AxisY.AxisTitle.SetTitle("Y Axis");
        axis.DataType = Data.DATA_TYPE_MARKER;

        // Data set 1
        double[] y1 = new double[20];
        for (int k = 0; k < y1.Length; k++) y1[k] = r.NextDouble();
        Data data1 = new Data(axis, y1);
        data1.MarkerType = Data.MARKER_TYPE_FILLED_SQUARE;
        data1.MarkerColor = Color.Green;

        // Data set 2
        double[] y2 = new double[20];
        for (int k = 0; k < y2.Length; k++) y2[k] = r.NextDouble();
        Data data2 = new Data(axis, y2);
        data2.MarkerType = Data.MARKER_TYPE_PLUS;
        data2.MarkerColor = Color.Blue;
    }

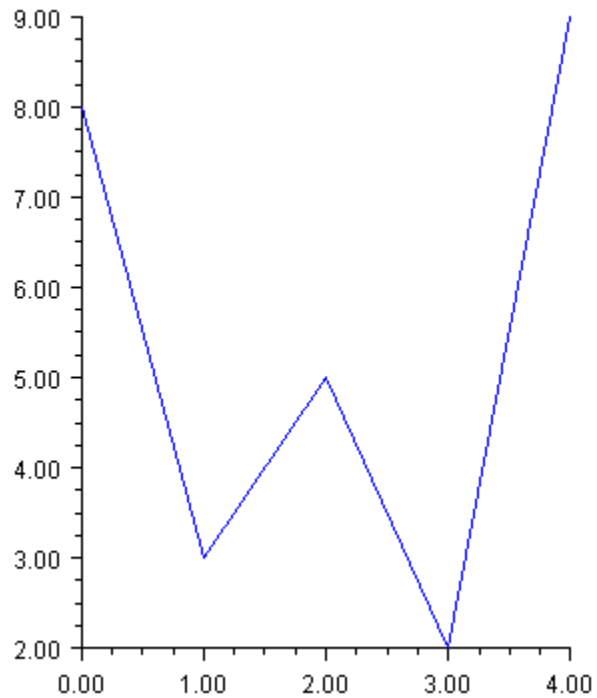
    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleScatter());
    }
}
```

Line Plot

A line plot consists of points by lines. The lines can be formatted using the “[Line Attributes](#)” on page 108.

Simple Line Plot

This example shows a simple line plot. The [Data](#) node is created using an array of y -values. The x -values default to 0, 1, The `DataType` attribute is set to `DATA_TYPE_LINE` to make this a line chart. The look of the line is controlled by the line attributes. Here the [LineColor](#) attribute is set to blue.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleSimpleLine : FrameChart {

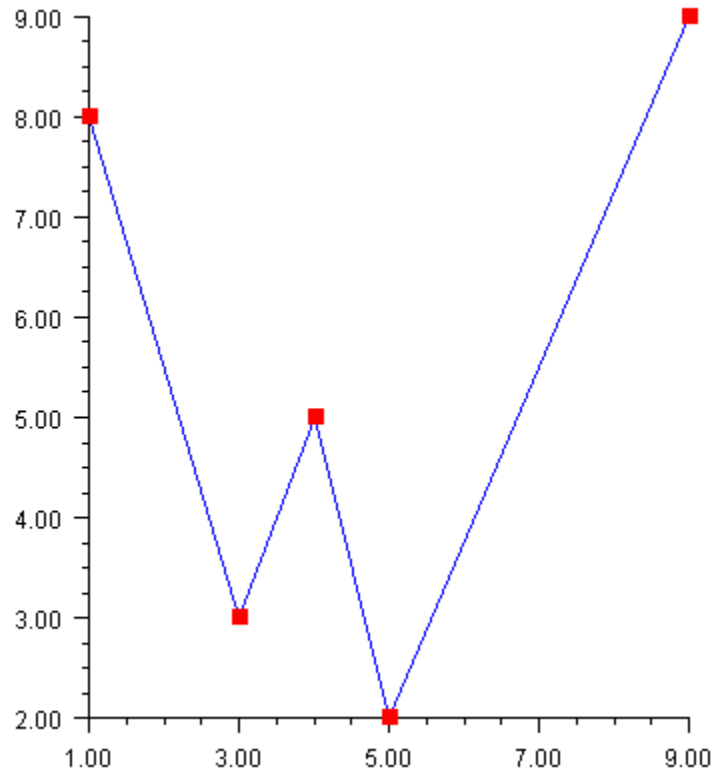
    public SampleSimpleLine() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[] y = new double[] {8, 3, 5, 2, 9};
        Data data1 = new Data(axis, y);
        data1.DataType = Data.DATA_TYPE_LINE;
        data1.LineColor = Color.Blue;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleSimpleLine());
    }
}
```


Mixed Line and Marker Plot

The `DataType` attribute can be set using “or” syntax to combine types. In this example, it is set to [DATA_TYPE_LINE](#) | [DATA_TYPE_MARKER](#). This example also explicitly sets both the *x*-value and the *y*-value of the data points. Note that the *x*-values do not have to be uniformly spaced.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleLineMarker : FrameChart {

    public SampleLineMarker() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[] x = new double[] {1, 3, 4, 5, 9};
        double[] y = new double[] {8, 3, 5, 2, 9};
        Data data1 = new Data(axis, x, y);
        data1.DataType = Data.DATA_TYPE_LINE | Data.DATA_TYPE_MARKER;
        data1.LineColor = Color.Blue;
        data1.MarkerColor = Color.Red;
    }
}
```

```

        data1.MarkerType = Data.MARKER_TYPE_FILLED_SQUARE;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleLineMarker());
    }
}

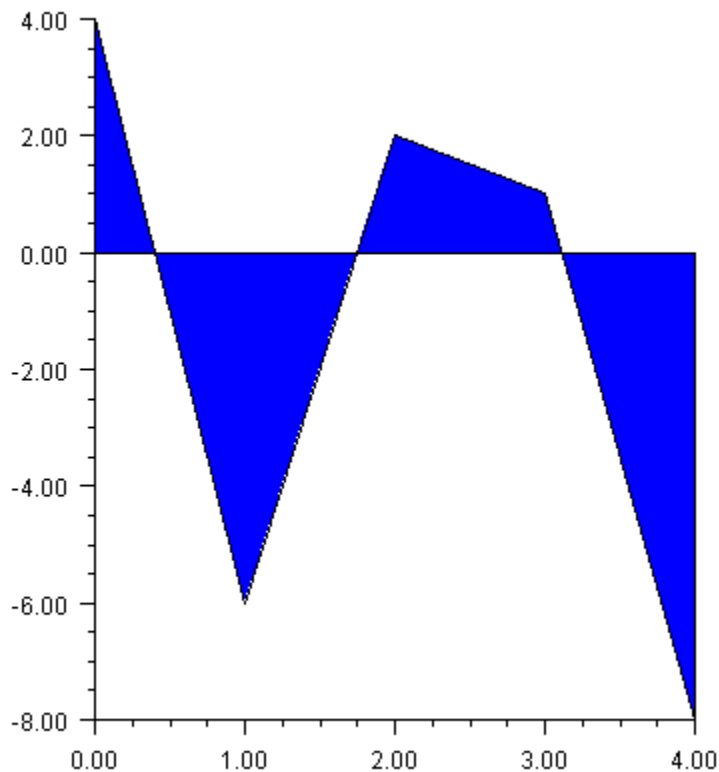
```

Area Plot

Area plots are similar to line plots, but with the area between the line and a reference line filled in. An area plot is created if the [DATA_TYPE_FILL](#) bit is on in the value of the `DataType` attribute. The default reference line is $y = 0$. The location of the reference line can be changed from 0 by setting the [Reference](#) property. The [Fill Area Attributes](#) determine how the area is filled.

Simple Area Plot

This example draws a simple area plot. The default value of the [FillType](#) attribute is [FILL_TYPE_SOLID](#). The example sets the [FillColor](#) attribute to [Color.Blue](#). So the area between the line $y = 0$ is solid blue



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleArea : FrameChart {

    public SampleArea() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[] y = new double[] {4, -6, 2, 1, -8};
        Data data1 = new Data(axis, y);
        data1.DataType = Data.DATA_TYPE_FILL;
        data1.FillColor = Color.Blue;
    }

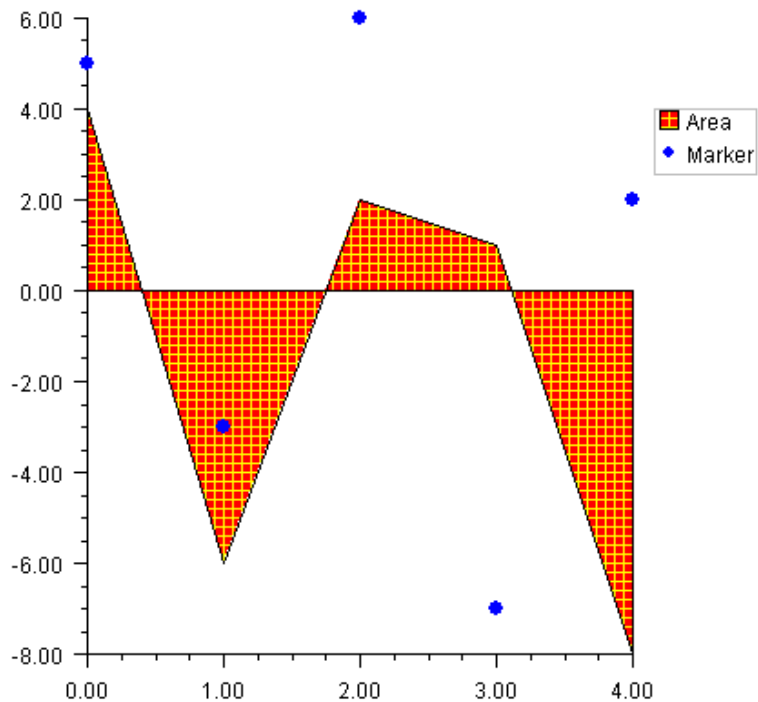
    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleArea());
    }
}
```

Painted Area Example

This example shows an area chart filled in with a painted texture. The texture is created by a static method [FillPaint.Crosshatch](#).

A second data set is plotted as a set of markers.

The [Legend](#) node is painted in this example and has entries for both the filled area data set and the marker data set.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleAreaPaint : FrameChart {

    public SampleAreaPaint() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        chart.Legend.IsVisible = true;

        double[] y = new double[] {4, -6, 2, 1, -8};
        Data data1 = new Data(axis, y);
        data1.SetTitle("Area");
        data1.DataType = Data.DATA_TYPE_FILL;
        data1.FillType = Data.FILL_TYPE_PAINT;
        data1.SetFillPaint(FillPaint.Crosshatch(
            10, 5, Color.Red, Color.Yellow));

        double[] y2 = {5, -3, 6, -7, 2};
        Data data2 = new Data(axis, y2);
        data2.SetTitle("Marker");
        data2.DataType = Data.DATA_TYPE_MARKER;
        data2.MarkerColor = Color.Blue;
        data2.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
    }
}
```

```
public static void Main(string[] argv) {  
    System.Windows.Forms.Application.Run(new SampleAreaPaint());  
}  
}
```

Attribute Reference

The attribute `Reference` defines the reference line. If its value is a , then the reference line is $y = a$. Its default value is 0.

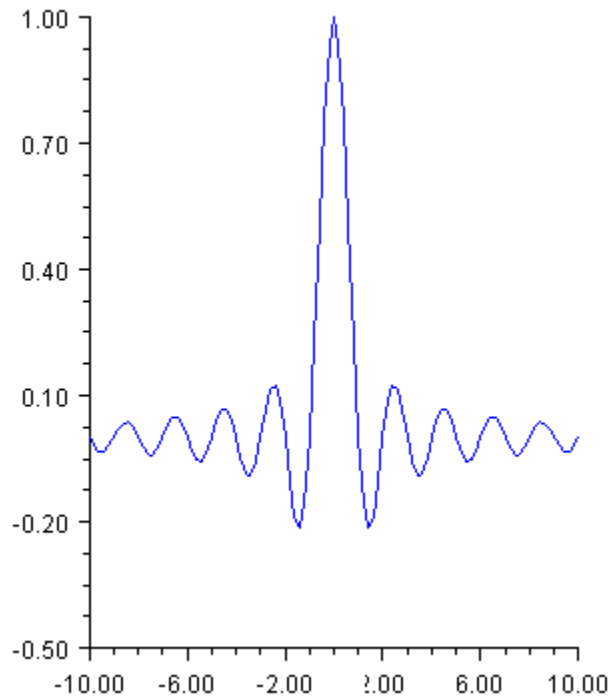
Function Plot

A function plot shows the value of a function $f(x)$ over an interval $[a,b]$. The function must be defined as an implementation of the [ChartFunction](#) interface. A [Data](#) node constructor creates a line chart from the function. The look of the function is controlled by the line attributes.

The `ChartFunction` interface requires that the function name be "F", that the function has a single double argument and that it returns a double.

Example

This example plots the sinc function on the interval $[-10,10]$. The sinc function is defined to be $\sin(\pi x)/\pi x$. In this example, `Sinc` is a class that implements `ChartFunction`. This is required by the function `Data` constructor. In the code, the case $x = 0$ is handled specially to avoid returning [NaN](#).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System;
using System.Drawing;

public class SampleFunction : FrameChart {

    public SampleFunction() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        Data data = new Data(axis, new sinc(), -10.0, 10.0);
        data.LineColor = Color.Blue;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleFunction());
    }
}

class sinc : ChartFunction {
    public double F(double x) {
        if (x == 0.0) return 1.0;
        return Math.Sin(Math.PI*x) / (Math.PI*x);
    }
}
```

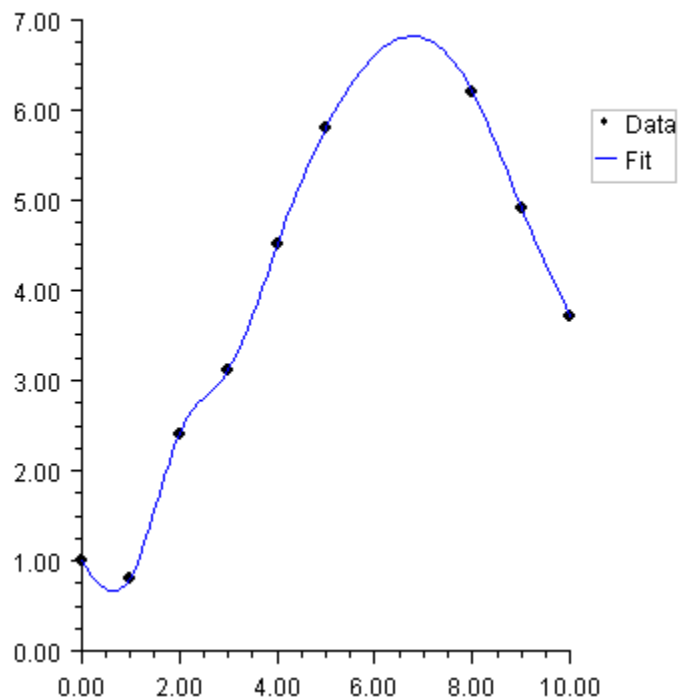
```
}  
}
```

Histogram Example

For another example of a [ChartFunction](#), see [Histogram](#)" on page 54.

Spline Chart

This example shows raw data points, as markers, and their fit to a shape preserving spline. The spline is computed using [CsShape](#) found in the IMSL C# Numerical Library Math namespace (which extends [Spline](#)). The [ChartSpline](#) class wraps the [Spline](#) into a [ChartFunction](#). This example also enables the [Legend](#).



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using Imsl.Math;  
using System.Drawing;  
  
public class SampleSpline : FrameChart {  
    public SampleSpline() {  
        Chart chart = this.Chart;  
    }  
}
```

```

AxisXY axis = new AxisXY(chart);
chart.Legend.IsVisible = true;

double[] x = {0, 1, 2, 3, 4, 5, 8, 9, 10};
double[] y = {1.0, 0.8, 2.4, 3.1, 4.5, 5.8, 6.2, 4.9, 3.7};
Data dataMarker = new Data(axis, x, y);
dataMarker.SetTitle("Data");
dataMarker.DataType = Data.DATA_TYPE_MARKER;
dataMarker.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;

CsShape spline = new CsShape(x, y);
Data dataSpline = new Data(axis, new ChartSpline(spline),
    0.0, 10.0);
dataSpline.SetTitle("Fit");
dataSpline.LineColor = Color.Blue;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleSpline());
}
}

```

Log and SemiLog Plot

In a semilog plot the y -axis is logarithmically scaled, while the x -axis is linearly scaled. In a log-log plot both axes are logarithmically scaled.

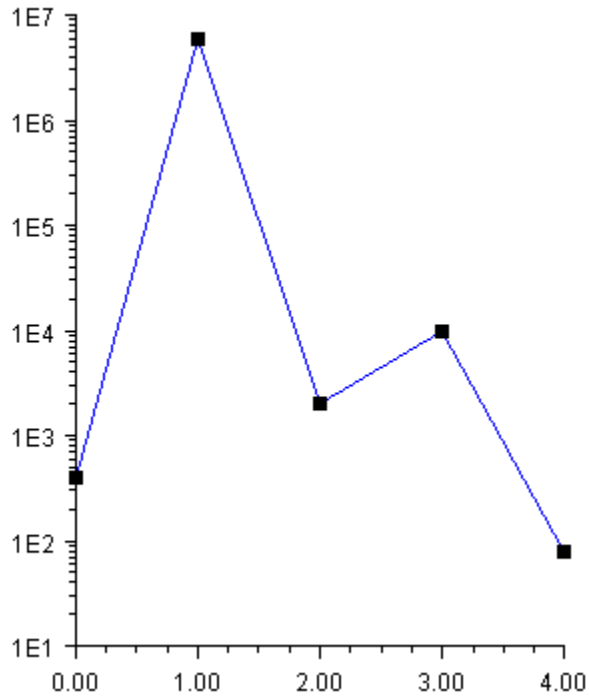
SemiLog Plot

In this example, data is plotted as lines and markers on a semilog axis.

To set up the y -axis as a logarithmic axis:

- the [Transform](#) attribute is set to [TRANSFORM_LOG](#).
- the [Density](#) on page 124 attribute is set to 9. Density is the number of minor ticks between major ticks. It is 9 because base 10 is used and the major tick marks are not counted.

The `TextFormat`, used by [AxisLabel](#), is changed to use scientific notation (see “[Text Attributes](#)”). The default decimal format would result in large numbers written with many zeros.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleSemiLog : FrameChart {

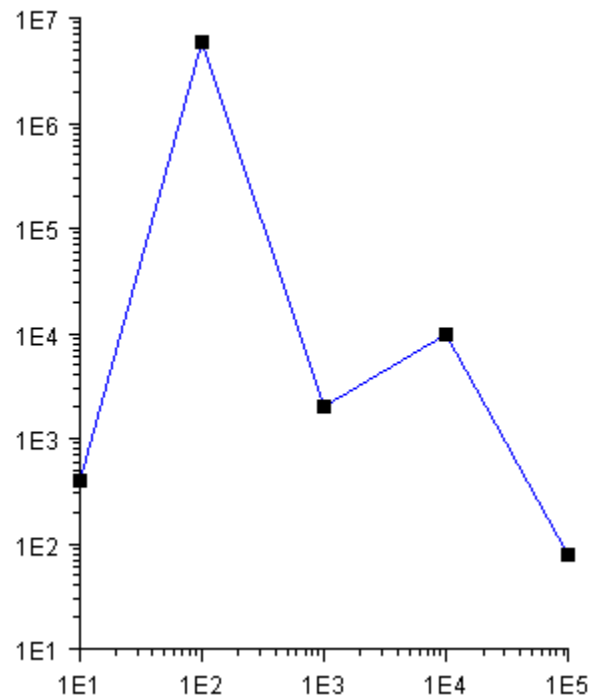
    public SampleSemiLog() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        axis.AxisY.Transform = Axis.TRANSFORM_LOG;
        axis.AxisY.Density = 9;
        axis.AxisY.TextFormat = "0.E0";

        double[] y = new double[] {4e2, 6e6, 2e3, 1e4, 8e1};
        Data data1 = new Data(axis, y);
        data1.DataType = Data.DATA_TYPE_LINE | Data.DATA_TYPE_MARKER;
        data1.LineColor = Color.Blue;
        data1.MarkerType = Data.MARKER_TYPE_FILLED_SQUARE;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleSemiLog());
    }
}
```

Log-Log Plot

A log-log plot is set up similarly as a semilog plot, except that the changes must be made to both the x -axis and the y -axis. In this example, the changes are made to the axis node and inherited by both the x and y -axis nodes.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleLogLog : FrameChart {

    public SampleLogLog() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        axis.Transform = Axis.TRANSFORM_LOG;
        axis.Density = 9;
        axis.TextFormat = "0.E0";

        double[] x = new double[] {1e1, 1e2, 1e3, 1e4, 1e5};
        double[] y = new double[] {4e2, 6e6, 2e3, 1e4, 8e1};
        Data data1 = new Data(axis, x, y);
        data1.DataType = Data.DATA_TYPE_LINE | Data.DATA_TYPE_MARKER;
        data1.LineColor = Color.Blue;
    }
}
```

```

    data1.MarkerType = Data.MARKER_TYPE_FILLED_SQUARE;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleLogLog());
}
}

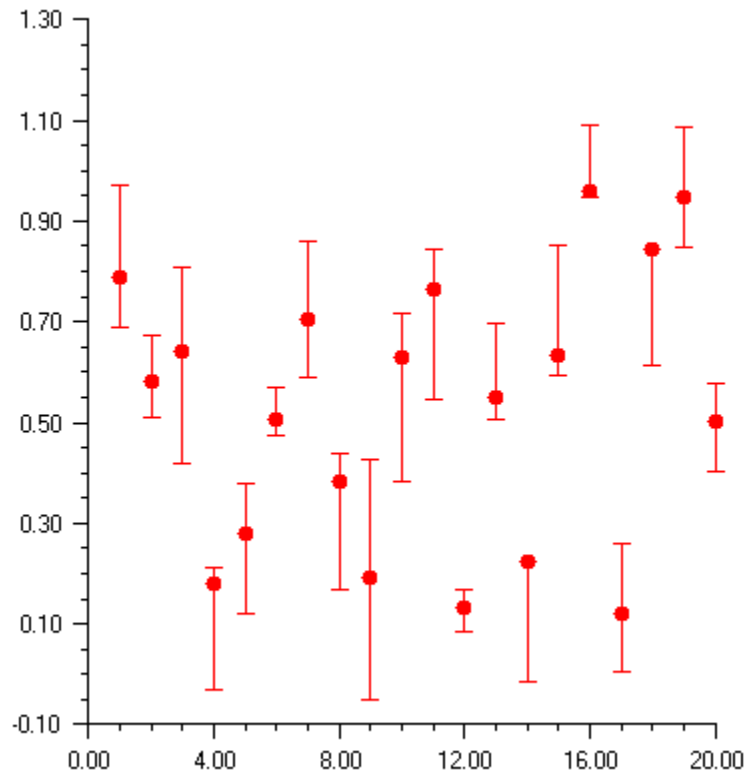
```

Error Bar Plot

Error bars are used to indicate the estimated error in a measurement. Errors bars indicate the uncertainty in the x and/or y values.

Vertical Error Bars

The most common error bar plot is one in which the errors are in the y -values. This example shows such an error bar plot. Note that the values of the low and high arguments are absolute y -values, not relative or percentage values.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;
using Imsl.Stat;

public class SampleErrorBar : FrameChart {

    public SampleErrorBar() {
        Random r = new Random(123457);

        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

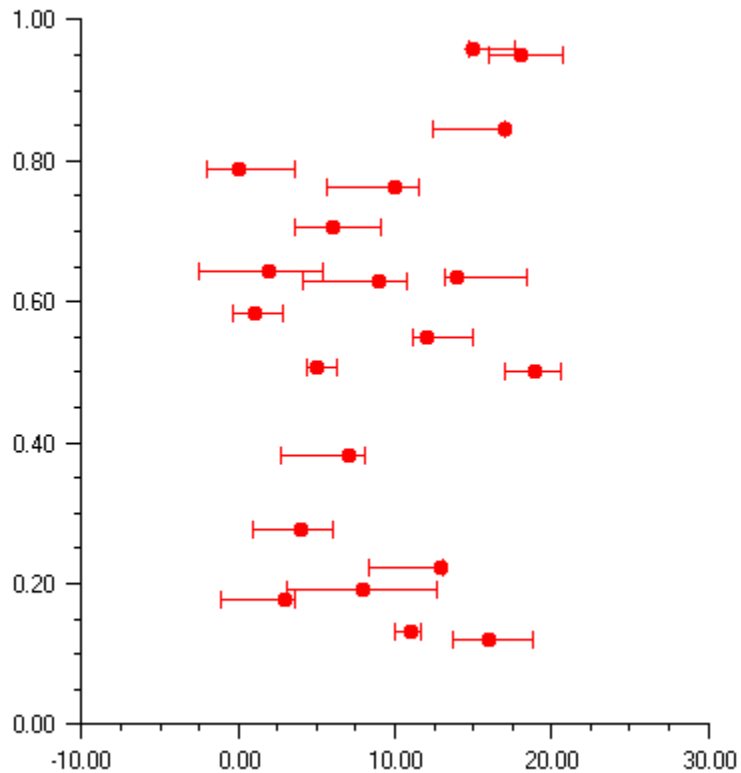
        // Generate a random data set, with random errors
        int n = 20;
        double[] x = new double[n];
        double[] y = new double[n];
        double[] low = new double[n];
        double[] high = new double[n];
        for (int k = 0; k < n; k++) {
            x[k] = k + 1;
            y[k] = r.NextDouble();
            low[k] = y[k] - 0.25*r.NextDouble();
            high[k] = y[k] + 0.25*r.NextDouble();
        }

        ErrorBar data = new ErrorBar(axis, x, y, low, high);
        data.DataType = ErrorBar.DATA_TYPE_ERROR_Y |
            Data.DATA_TYPE_MARKER;
        data.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
        data.MarkerColor = Color.Red;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleErrorBar());
    }
}
```

Horizontal Error Bars

It is also possible to have horizontal error bars, indicating errors in x , as shown in this example.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;
using Imsl.Stat;

public class SampleHorizontalErrorBar : FrameChart {

    public SampleHorizontalErrorBar() {
        Random r = new Random(123457);

        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        // Generate a random data set, with random errors
        int n = 20;
        double[] x = new double[n];
```

```

double[] y = new double[n];
double[] low = new double[n];
double[] high = new double[n];
for (int k = 0; k < n; k++) {
    x[k] = k;
    y[k] = r.NextDouble();
    low[k] = x[k] - 5.0*r.NextDouble();
    high[k] = x[k] + 5.0*r.NextDouble();
}

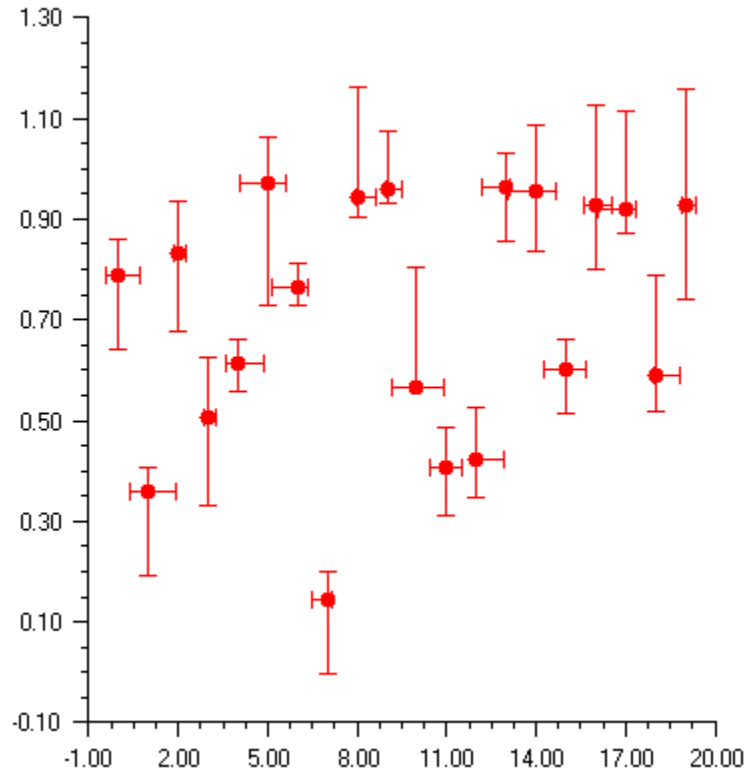
ErrorBar data = new ErrorBar(axis, x, y, low, high);
data.DataType = ErrorBar.DATA_TYPE_ERROR_X |
    Data.DATA_TYPE_MARKER;
data.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
data.MarkerColor = Color.Red;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(
        new SampleHorizontalErrorBar());
}
}

```

Mixed Error Bars

To show errors in both x and y , it is necessary to create both vertical and horizontal error bar objects. This example shows such a chart.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;
using Imsl.Stat;

public class SampleMixedErrorBar : FrameChart {

    public SampleMixedErrorBar() {
        Random r = new Random(123457);

        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        // Generate a random data set, with random errors
        int n = 20;
        double[] x = new double[n];
        double[] y = new double[n];
        double[] xlow = new double[n];
        double[] xhigh = new double[n];
        double[] ylow = new double[n];
        double[] yhigh = new double[n];
        for (int k = 0; k < n; k++) {
```

```

        x[k] = k;
        y[k] = r.NextDouble();
        xlow[k] = x[k] - r.NextDouble();
        xhigh[k] = x[k] + r.NextDouble();
        ylow[k] = y[k] - 0.25*r.NextDouble();
        yhigh[k] = y[k] + 0.25*r.NextDouble();
    }

    ErrorBar dataY = new ErrorBar(axis, x, y, ylow, yhigh);
    dataY.DataType = ErrorBar.DATA_TYPE_ERROR_Y | Data.DATA_TYPE_MARKER;
    dataY.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
    dataY.MarkerColor = Color.Red;

    ErrorBar dataX = new ErrorBar(axis, x, y, xlow, xhigh);
    dataX.DataType = ErrorBar.DATA_TYPE_ERROR_X;
    dataX.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
    dataX.MarkerColor = Color.Red;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleMixedErrorBar());
}
}

```

High-Low-Close Plot

High-Low-Close plots are used to show stock prices. They are created using the [HighLowClose](#) class.

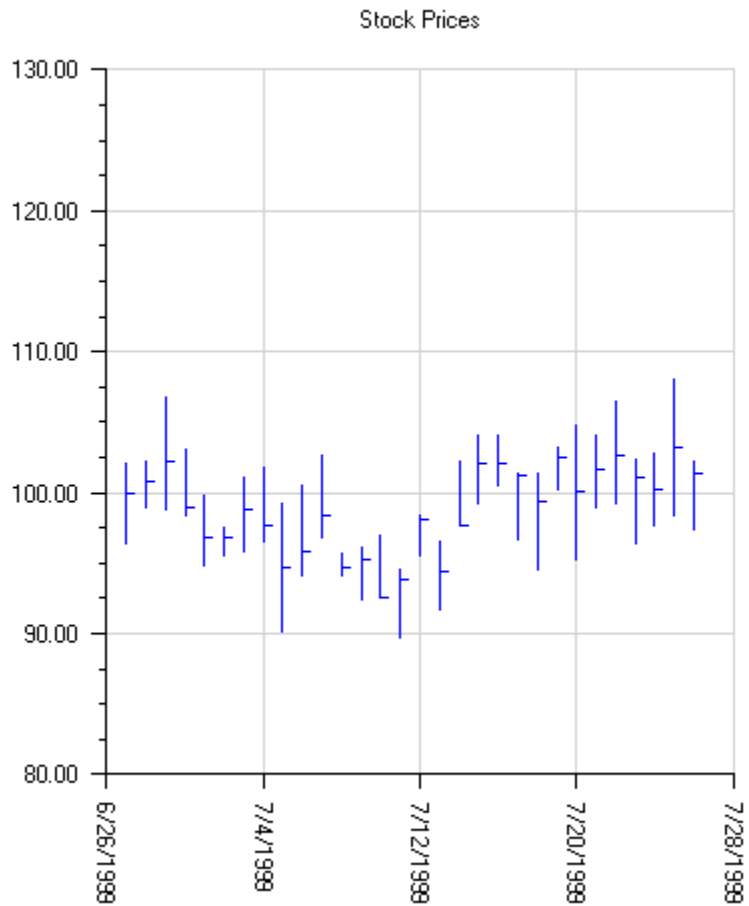
The markers can be formatted using the attribute `MarkerColor`.

In a high-low-close plot the vertical line represent`s the high and low values. The close value is represented by a “tick” to the right. The open value, if present, is represented by a tick to the left.

The [HighLowClose.SetDateAxis](#) method will configure the *x*-axis for dates. This turns off autoscaling of the axis.

Example

In this example, random security prices are computed in the `CreateData` method. The time axis is prepared by calling [HighLowClose.SetDateAxis](#).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System;
using System.Drawing;

public class SampleHighLowClose : FrameChart {
    private double[] high, low, close;

    public SampleHighLowClose() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        // Date is June 27, 1999
        DateTime date = new DateTime(1999, 6, 27);

        int n = 30;
        CreateData(n);
    }
}
```

```

// Create an instance of a HighLowClose Chart
HighLowClose hilo = new HighLowClose(axis, date, high,
    low, close);
hilo.MarkerColor = Color.Blue;

// Set the HighLowClose Chart Title
chart.ChartTitle.SetTitle("Stock Prices");

// Setup the x axis
Axis1D axisX = axis.AxisX;

// Set the text angle for the X axis labels
axisX.AxisLabel.TextAngle = 270;

// Setup the time axis
hilo.SetDateAxis("d");

// Turn on grid and make it light gray
axisX.Grid.IsVisible = true;
axisX.Grid.LineColor = Color.LightGray;
axis.AxisY.Grid.IsVisible = true;
axis.AxisY.Grid.LineColor = Color.LightGray;
}

private void CreateData(int n) {
    high = new double[n];
    low = new double[n];
    close = new double[n];
    Random r = new Random(123457);
    for (int k = 0; k < n; k++) {
        double f = r.NextDouble();
        if (k == 0) {
            close[0] = 100;
        } else {
            close[k] = (0.95+0.10*f)*close[k-1];
        }
        high[k] = close[k]*(1+0.05*r.NextDouble());
        low[k] = close[k]*(1-0.05*r.NextDouble());
    }
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(
        new SampleHighLowClose());
}
}

```

Candlestick Chart

A [Candlestick](#) chart is used to show stock price. Each candlestick shows the stock's high, low, opening and closing prices.

The `Candlestick` constructors create two child `CandlestickItem` nodes. One is for the up days and one is for the down days. A day is an up day if the closing price is greater than the opening price. The `Up` and `Down` accessor properties can be used to retrieve these nodes.

The line (“whisker”) part of a candlestick shows the stock’s high and low prices. The whiskers can be formatted using the line attributes (see “[Line Attributes](#)” on page 108).

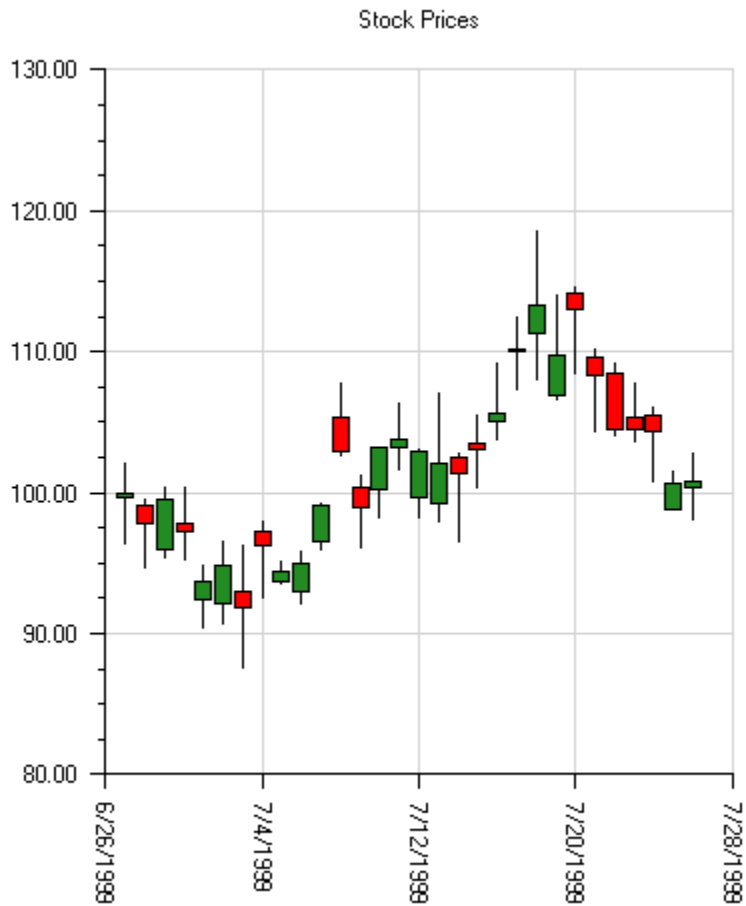
The body of a candlestick shows the stock’s opening and closing prices. The body color is used to flag if the top of the body is the closing price (up day) or the opening price (down day). The fill area attributes determine how the body is drawn (see “[Fill Area Attributes](#)” on page 111). By default, up days are white and down days are black.

The width of a candlestick is controlled by the `MarkerSize` attribute (see [Attribute MarkerSize](#) on page 110).

Example

In this example, random security prices are computed in the `CreateData` method. The time axis is prepared by calling `SetDateAxis`.

The up days are colored green and the down days are colored red.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System;
using System.Drawing;

public class SampleCandlestick : FrameChart {
    private double[] high, low, open, close;

    public SampleCandlestick() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        // Date is June 27, 1999
        DateTime date = new DateTime(1999, 6, 27);

        int n = 30;
        CreateData(n);
    }
}
```

```

// Create an instance of a Candlestick Chart
Candlestick stick = new Candlestick(axis, date, high, low,
    close, open);

// show up days in green and down days in red
stick.Up.FillColor = Color.ForestGreen;
stick.Down.FillColor = Color.Red;

// Set the HighLowClose Chart Title
chart.ChartTitle.SetTitle("Stock Prices");

// Setup the time axis
stick.SetDateAxis("d");

// Turn on grid and make it light gray
axis.AxisX.Grid.IsVisible = true;
axis.AxisX.Grid.LineColor = Color.LightGray;
axis.AxisY.Grid.IsVisible = true;
axis.AxisY.Grid.LineColor = Color.LightGray;
}

private void CreateData(int n) {
    high = new double[n];
    low = new double[n];
    close = new double[n];
    open = new double[n];
    Random r = new Random(123457);
    for (int k = 0; k < n; k++) {
        double f = r.NextDouble();
        if (k == 0) {
            close[0] = 100;
        } else {
            close[k] = (0.95+0.10*f)*close[k-1];
        }
        high[k] = close[k]*(1+0.05*r.NextDouble());
        low[k] = close[k]*(1-0.05*r.NextDouble());
        open[k] = low[k] + r.NextDouble()*(high[k]-low[k]);
    }
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleCandlestick());
}
}

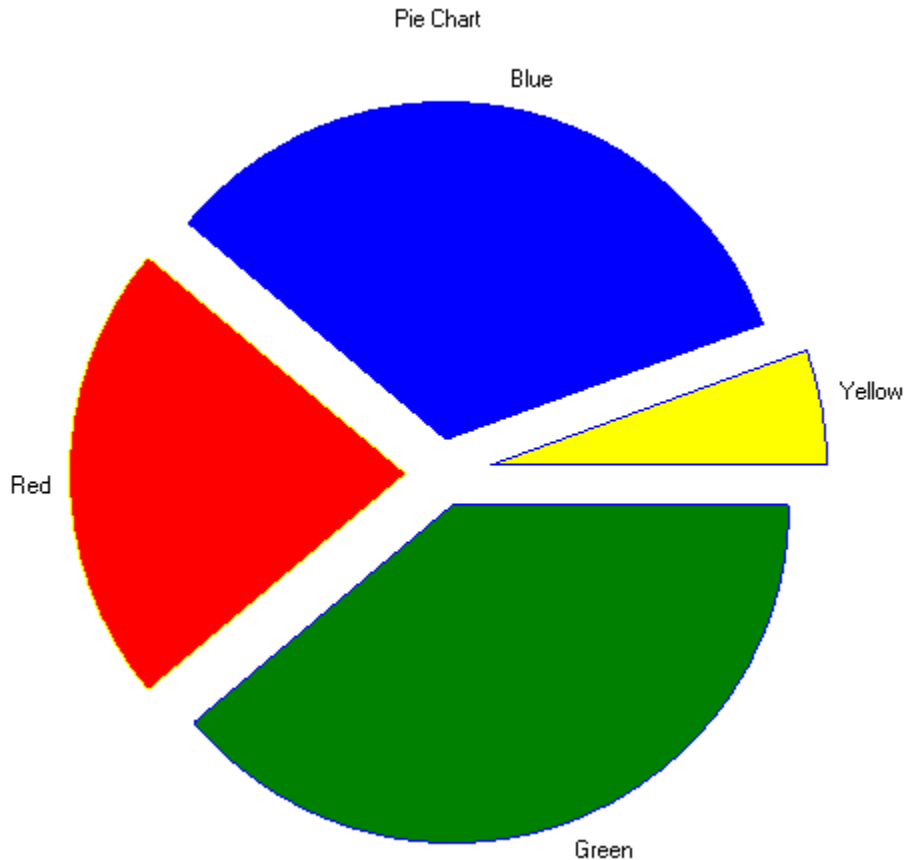
```

Pie Chart

A pie chart is a graphical way to organize data. This section describes the construction of a pie chart.

Example

The [FrameChart](#) class is used to create a frame containing a [Chart](#) node. A [Pie](#) node is then created as a child of the [Chart](#) node. The [Pie](#) node constructor creates [PieSlice](#) nodes as its children. The number of [PieSlice](#) nodes created is `y.Length`, here equal to 4. After the [PieSlice](#) nodes are created they are retrieved from the [Pie](#) object and customized by setting attributes.



The [LabelType](#) attribute is set in the pie node. The pie node itself does not use this attribute, but from there it is inherited by all of the [PieSlice](#) nodes.

The [Title](#) attribute is set in each [PieSlice](#) node. This is the slice label. It is used to label the slice only if the slice's [LabelType](#) attribute is [LABEL_TYPE_TITLE](#).

The [FillColor](#) attribute is also set in each slice. This determines the color of the slice. Since the default value of [FillColor](#) is black, it is generally recommended that [FillColor](#) be set in each slice.

The [FillOutlineColor](#) attribute sets the border color of each slice. In this example it is set in the pie node to be blue and set in the `slice[1]` node to be yellow. All except `slice[1]` are outlined in blue, and `slice[1]` is outlined in yellow.

The [Explode](#) attribute moves a pie slice out from the center. Its default value is 0, which puts the slice vertex in the center. A value of 1.0 would put the slice vertex on the circumference.

[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SamplePieChart : FrameChart
{
    public SamplePieChart()
    {
        Chart chart = this.Chart;
        chart.ChartTitle.SetTitle("Pie Chart");

        double[] y = new double[] {35, 20, 30, 5};
        Pie pie = new Pie(chart, y);
        pie.LabelType = Pie.LABEL_TYPE_TITLE;
        pie.FillOutlineColor = Color.Blue;
        pie.SetViewport(0.0, 1.0, 0.0, 1.0);

        PieSlice[] slice = pie.GetPieSlice();

        slice[0].FillColor = Color.Green;
        slice[0].SetTitle("Green");
        slice[0].Explode = 0.1;

        slice[1].FillColor = Color.Red;
        slice[1].SetTitle("Red");
        slice[1].FillOutlineColor = Color.Yellow;
        slice[1].Explode = 0.1;

        slice[2].FillColor = Color.Blue;
        slice[2].SetTitle("Blue");
        slice[2].Explode = 0.1;

        slice[3].FillColor = Color.Yellow;
        slice[3].SetTitle("Yellow");
        slice[3].Explode = 0.15;
    }

    public static void Main(string[] argv)
    {
        System.Windows.Forms.Application.Run(new SamplePieChart());
    }
}
```

Box Plot

[BoxPlot](#) plots are used to show statistics about multiple groups of observations.

For each group of observations, the box limits represent the lower quartile (25-th percentile) and upper quartile (75-th percentile). The median is displayed as a line across the box. Whiskers are drawn from the upper quartile to the upper adjacent value, and from the lower quartile to the lower adjacent value.

Optional notches may be displayed to show a 95 percent confidence interval about the median, at

$$\pm 1.58 \text{ IRQ} / \sqrt{n}$$

where *IRQ* is the interquartile range and *n* is the number of observations. Outside and far outside values may be displayed as symbols. Outside values are outside the inner fence. Far out values are outside the outer fence.

The `BoxPlot` has several child nodes. Any of these nodes can be disabled by setting their [IsVisible](#) property to `false`.

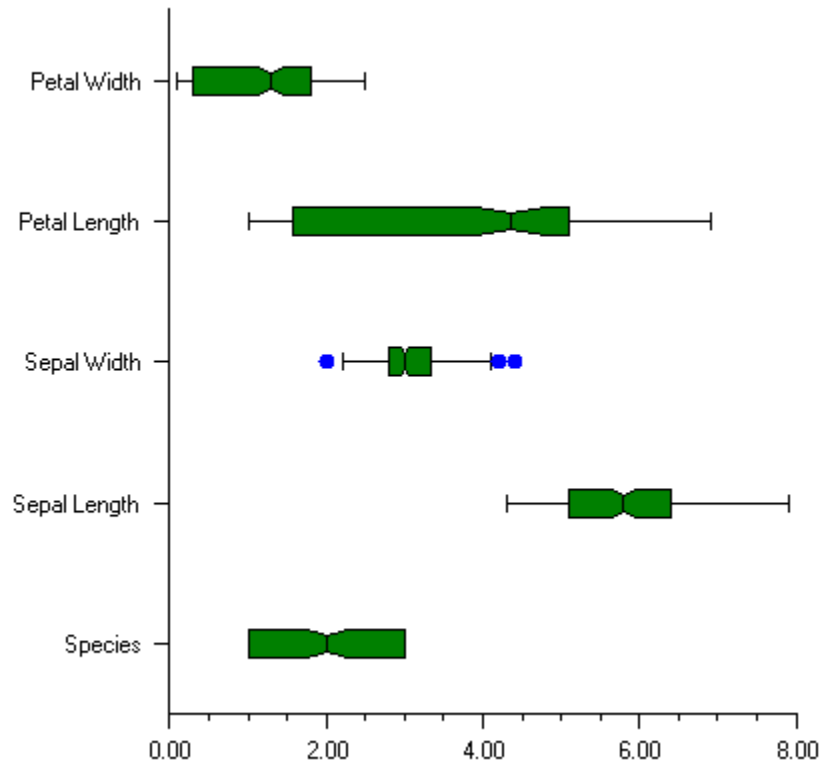
- The [Bodies](#) node has the main body of the box plot elements. Its fill attributes determine the drawing of (notched) rectangle (see “[Fill Area Attributes](#)” on page 111). Its line attributes determine the drawing of the median line. The width of the box is controlled by the `MarkerSize` attribute (see [Attribute MarkerSize](#) on page 110).
- The [Whiskers](#) node draws the lines to the upper and lower quartile. Its drawing is affected by the marker attributes.
- The [FarMarkers](#) node holds the far markers. Its drawing is affected by the marker attributes.
- The [OutsideMarkers](#) node holds the outside markers. Its drawing is affected by the marker attributes.

Example

In this example, the Fisher iris data set is read from a file and a Box plot is created from data. The data is in a file called `FisherIris.csv` in the same directory as this class.

The y-axis labels are taken from the column names.

The boxes are colored green; the markers are all filled circles. The outside markers are blue and the far outside markers would be red, if there were any.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;
using System.IO;

public class SampleBoxPlot : FrameChart {
    private double[][] irisData;
    private string[] labels;

    public SampleBoxPlot() {
        ReadData("FisherIris.csv");

        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        BoxPlot boxPlot = new BoxPlot(axis, irisData);
        boxPlot.BoxPlotType = BoxPlot.BOXPLOT_TYPE_HORIZONTAL;
        boxPlot.SetLabels(labels);
        boxPlot.Bodies.FillColor = Color.Green;
        boxPlot.MarkerType = BoxPlot.MARKER_TYPE_FILLED_CIRCLE;
        boxPlot.OutsideMarkers.MarkerColor = Color.Blue;
        boxPlot.FarMarkers.MarkerColor = Color.Red;
        boxPlot.Notch = true;
    }
}
```

```

}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleBoxPlot());
}

private void ReadData(string fileName) {
    int nColumns = 5;
    int nObs = 150;
    irisData = new double[nColumns][];
    for (int i = 0; i < nColumns; i++) irisData[i] =
        new double[nObs];

    string line;
    string[] tokens;
    int lineCount = 0;
    StreamReader sr = new StreamReader(fileName);
    line = sr.ReadLine();
    labels = line.Split(',');
    for (int i = 0; i < nObs; i++) {
        line = sr.ReadLine();
        tokens = line.Split(',');
        for (int j = 0; j < nColumns; j++) {
            irisData[j][lineCount] =
                double.Parse(tokens[j].Trim());
        }
        lineCount++;
    }
}
}
}

```

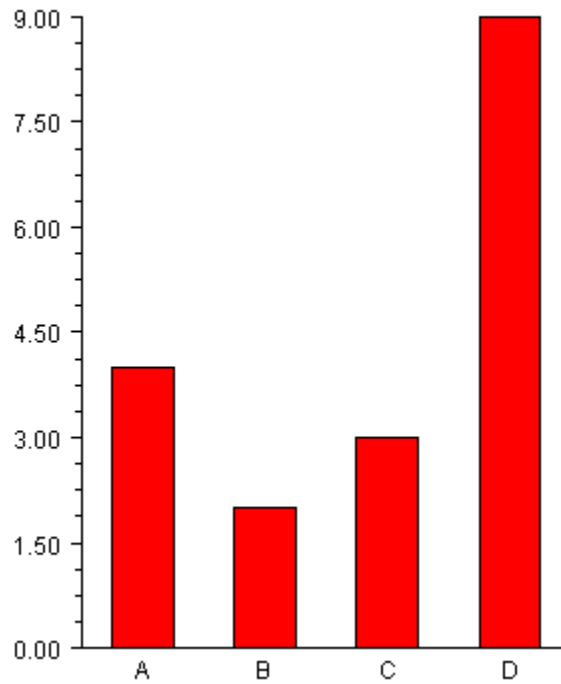
Bar Chart

The class [Bar](#) is used to create bar charts and histograms. This page describes the construction of labeled bar charts. For a discussion of histograms, see “[Histogram](#)” on page 54.

Simple Bar Chart

The following code creates this labeled bar chart. The [BarType](#) attribute can be either [BAR_TYPE_VERTICAL](#) or [BAR_TYPE_HORIZONTAL](#). The method [SetLabels](#) sets the bar labels and adjusts the attributes of the axis to be appropriate for bar labels. The [SetLabels](#) method must be called after the [BarType](#) method, so that the correct axis has its attributes adjusted.

The drawing of the bars is controlled by the [FillType](#) and [FillOutlineType](#) attributes. By default [FillType](#) has the value [FILL_TYPE_SOLID](#), so setting the associated attribute [FillColor](#) to red causes solid red bars to be drawn.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleBar : FrameChart {

    public SampleBar() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[] y = new double[] {4, 2, 3, 9};
        Bar bar = new Bar(axis, y);
        bar.BarType = Bar.BAR_TYPE_VERTICAL;
        bar.SetLabels(new string[] {"A", "B", "C", "D"});
        bar.FillColor = Color.Red;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleBar());
    }
}
```

Attribute BarGap

The [BarGap](#) attribute sets the gap between bars in a group. A gap of 1.0 means that space between bars is the same as the width of an individual bar in the group. Its default value is 0.0, meaning there is no space between groups.

Attribute BarWidth

The [BarWidth](#) attribute sets the width of the groups of bars at each index. Its default value is 0.5. If the number of groups is increased, the width of each individual bar is reduced proportionately.

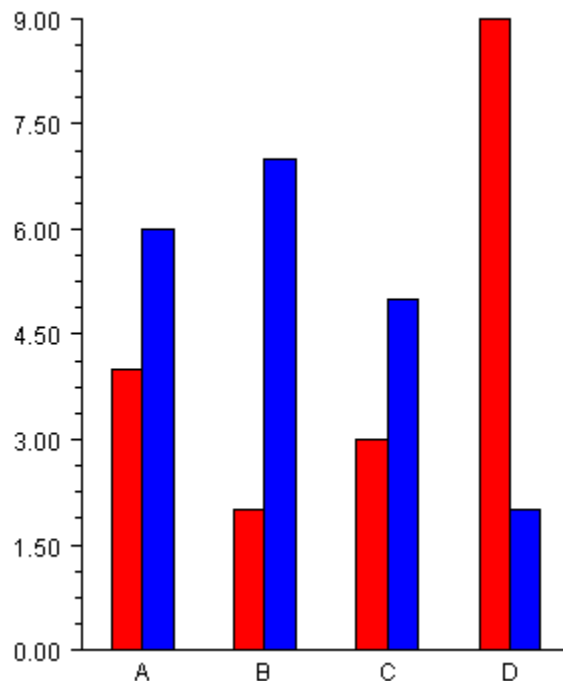
See [Histogram](#) on page 54 for an example of the use of the `BarWidth` attribute.

Grouped Bar Chart

In a grouped bar chart multiple sets of data are displayed as side-by-side bars.

The data argument to the constructor for a grouped bar chart is an `nGroups` by `nItems` array of `double`. In this example there are two groups, each containing four items. All of the groups must contain the same number of items.

The [GetBarSet\(int\)](#) method returns a [BarSet](#) object that is a collection of the [BarItems](#) that make up a given group. Here the bars in group 0 are set to red and those in group 1 are set to blue.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleBarGroup : FrameChart {

    public SampleBarGroup() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[][] y = new double[2][] {
            new double[] {4, 2, 3, 9},
            new double[] {6, 7, 5, 2}};
        Bar bar = new Bar(axis, y);
        bar.BarType = Bar.BAR_TYPE_VERTICAL;
        bar.SetLabels(new string[] { "A", "B", "C", "D" });
        bar.GetBarSet(0).FillColor = Color.Red;
        bar.GetBarSet(1).FillColor = Color.Blue;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleBarGroup());
    }
}
```

In the above grouped bar chart example, the `Bar` constructor creates a collection of chart nodes. For each group, it creates a `BarSet` node as its direct child. Each `BarSet` node has `BarItem` nodes as children, one for each bar in the set.

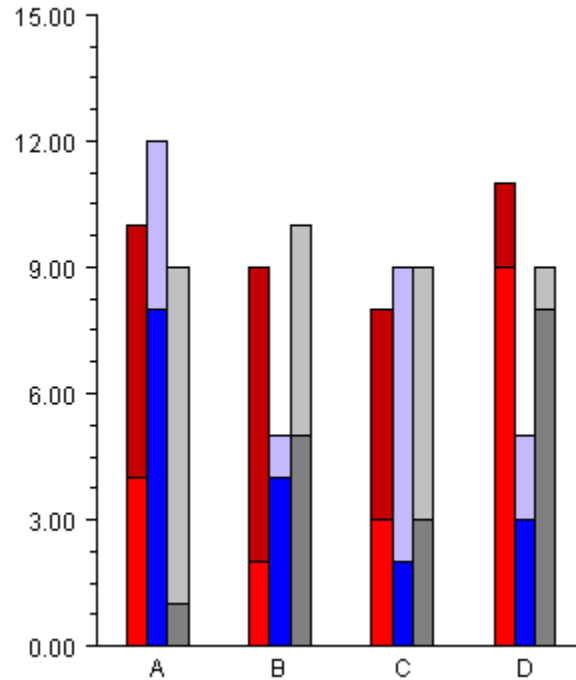
Stacked Grouped Bar Chart

The most general form of the bar chart is a stacked, grouped bar chart.

The data argument to the constructor for a stacked, grouped bar chart is an `nStacks` by `nGroups` by `nItems` array of `double`. In this example there are two stacks in three groups each containing four items. All of the stacks must contain the same number of groups and all of the groups must contain the same number of items.

The `GetBarSet(int, int)` method returns a `BarSet` object that is a collection of the `BarItems` that make up a given stack/group. Here within each group the stacks are set to shades of the same color.

A stacked bar chart, without groups, can be constructed as a stacked-grouped bar chart with one group



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleBarGroupStack : FrameChart {

    public SampleBarGroupStack() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        // y is a 2 by 3 by 4 array
        double[][][] y = new double[2][][] {
            new double[3][] {
                new double[] {4, 2, 3, 9},
                new double[] {8, 4, 2, 3},
                new double[] {1, 5, 3, 8}},
            new double[3][] {
                new double[] {6, 7, 5, 2},
                new double[] {4, 1, 7, 2},
                new double[] {8, 5, 6, 1}}};
        Bar bar = new Bar(axis, y);
        bar.BarType = Bar.BAR_TYPE_VERTICAL;
        bar.SetLabels(new string[] {"A","B","C","D"});
        // group 0 - shades of red
        bar.GetBarSet(0,0).FillColor = Color.Red;
        bar.GetBarSet(1,0).FillColor = Color.DarkRed;
        // group 1 - shades of blue
    }
}
```

```

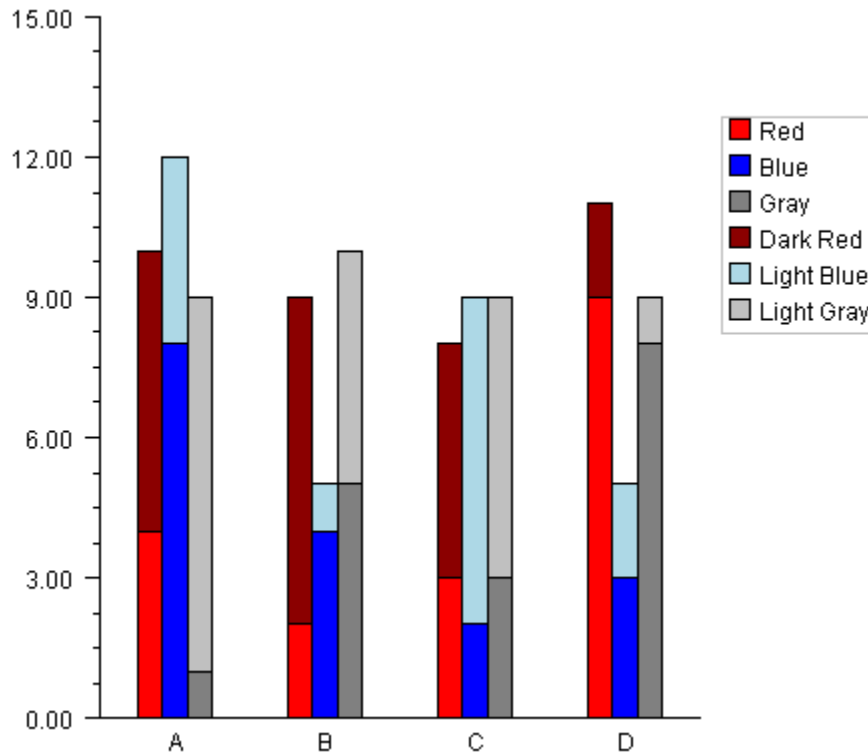
        bar.GetBarSet(0,1).FillColor = Color.Blue;
        bar.GetBarSet(1,1).FillColor = Color.LightBlue;
        // group 2 - shades of gray
        bar.GetBarSet(0,2).FillColor = Color.Gray;
        bar.GetBarSet(1,2).FillColor = Color.LightGray;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(
            new SampleBarGroupStack());
    }
}

```

Legend

The [Legend](#) for a bar chart is turned on by setting the Legend's [IsVisible](#) property to true and defining the [Title](#) attributes for the legend entries. The legend entries are the [BarSet](#) objects. The following example is the stacked, grouped bar example with the legend enabled.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleBarLegend : FrameChart {

    public SampleBarLegend() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        chart.Legend.IsVisible = true;
        // y is a 2 by 3 by 4 array
        double[][][] y = new double[2][][] {
            new double[3][] {
                new double[] {4, 2, 3, 9},
                new double[] {8, 4, 2, 3},
                new double[] {1, 5, 3, 8}},
            new double[3][] {
                new double[] {6, 7, 5, 2},
                new double[] {4, 1, 7, 2},
                new double[] {8, 5, 6, 1}}};
        Bar bar = new Bar(axis, y);
        bar.BarType = Bar.BAR_TYPE_VERTICAL;
        bar.SetLabels(new string[] { "A", "B", "C", "D" });
        // group 0 - shades of red
        bar.GetBarSet(0,0).SetTitle("Red");
        bar.GetBarSet(0,0).FillColor = Color.Red;
        bar.GetBarSet(1,0).SetTitle("Dark Red");
        bar.GetBarSet(1,0).FillColor = Color.DarkRed;
        // group 1 - shades of blue
        bar.GetBarSet(0,1).SetTitle("Blue");
        bar.GetBarSet(0,1).FillColor = Color.Blue;
        bar.GetBarSet(1,1).SetTitle("Light Blue");
        bar.GetBarSet(1,1).FillColor = Color.LightBlue;
        // group 2 - shades of gray
        bar.GetBarSet(0,2).SetTitle("Gray");
        bar.GetBarSet(0,2).FillColor = Color.Gray;
        bar.GetBarSet(1,2).SetTitle("Light Gray");
        bar.GetBarSet(1,2).FillColor = Color.LightGray;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleBarLegend());
    }
}
```

Contour Chart

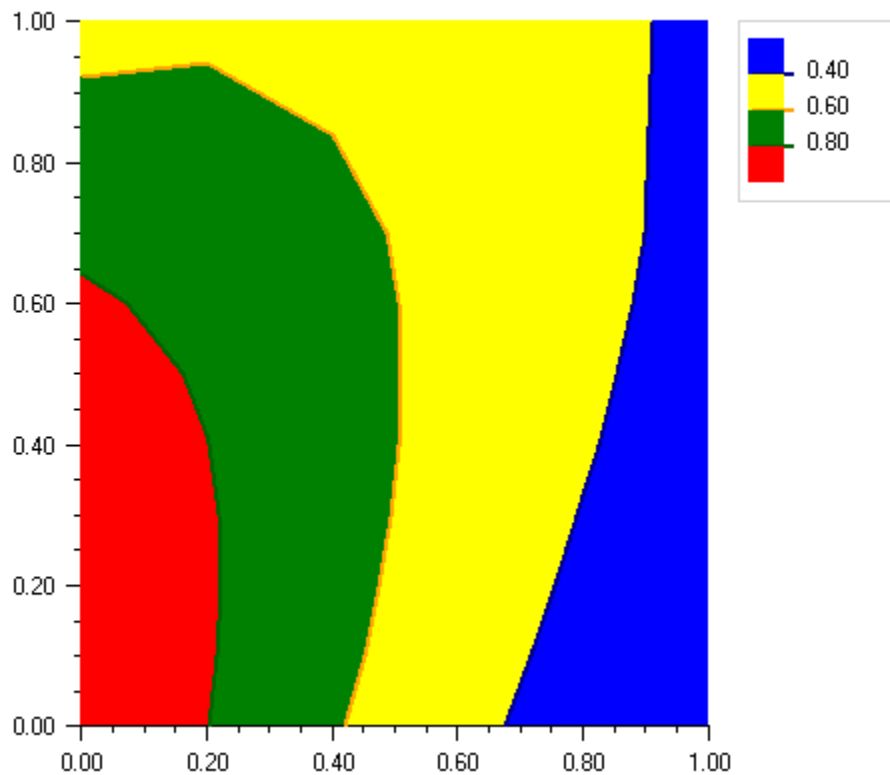
A [Contour](#) chart shows level curves of a two-dimensional function.

Example

The [FrameChart](#) class is used to create a frame containing a [Chart](#) node. A [Contour](#) node is then created as a child of the [Chart](#) node. The [Contour](#) node constructor creates [ContourLevel](#) nodes as its children. The number of [ContourLevel](#) nodes created is equal to the number of contour levels plus one, here equal to 4. After the [ContourLevel](#) nodes are created they are retrieved from the [Contour](#) object and customized by setting attributes.

The [FillColor](#) and [LineColor](#) attributes are set in each level. This determines the color of the fill area for the level and the color of the level curves. Since the default value of [FillColor](#) is black, it is generally recommended that [FillColor](#) be set in each level.

Each level corresponds to the area less than or equal to the contour level value and greater than the previous level, if any. So in this example, since the 0-th level value is 0.4, the area where the function is less than 0.4 is filled with blue (the level-0 fill color) and the level curve equal to 0.4 is drawn with dark blue, the level-0 line color.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using System;  
using System.Drawing;
```

```

public class SampleContour : FrameChart {

    public SampleContour() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[] xGrid = {0, 0.2, 0.4, 0.6, 0.8, 1.0};
        double[] yGrid = {0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 1.0};
        double[,] zData = new double[xGrid.Length, yGrid.Length];
        for (int i = 0; i < xGrid.Length; i++) {
            for (int j = 0; j < yGrid.Length; j++) {
                double x = xGrid[i];
                double y = yGrid[j];
                zData[i,j] = Math.Exp(-x) * Math.Cos(x-y);
            }
        }
        double[] level = {0.4, 0.6, 0.8};
        Contour contour = new Contour(axis, xGrid, yGrid,
            zData, level);
        contour.ContourLegend.IsVisible = true;
        contour.GetContourLevel(0).FillColor = Color.Blue;
        contour.GetContourLevel(1).FillColor = Color.Yellow;
        contour.GetContourLevel(2).FillColor = Color.Green;
        contour.GetContourLevel(3).FillColor = Color.Red;

        contour.GetContourLevel(0).LineColor = Color.DarkBlue;
        contour.GetContourLevel(1).LineColor = Color.Orange;
        contour.GetContourLevel(2).LineColor = Color.DarkGreen;
        contour.GetContourLevel(3).LineColor = Color.DarkRed;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleContour());
    }
}

```

Heatmap

A [Heatmap](#) divides a rectangle into subrectangles. The color of each subrectangle is determined by the value of a data array and a colormap.

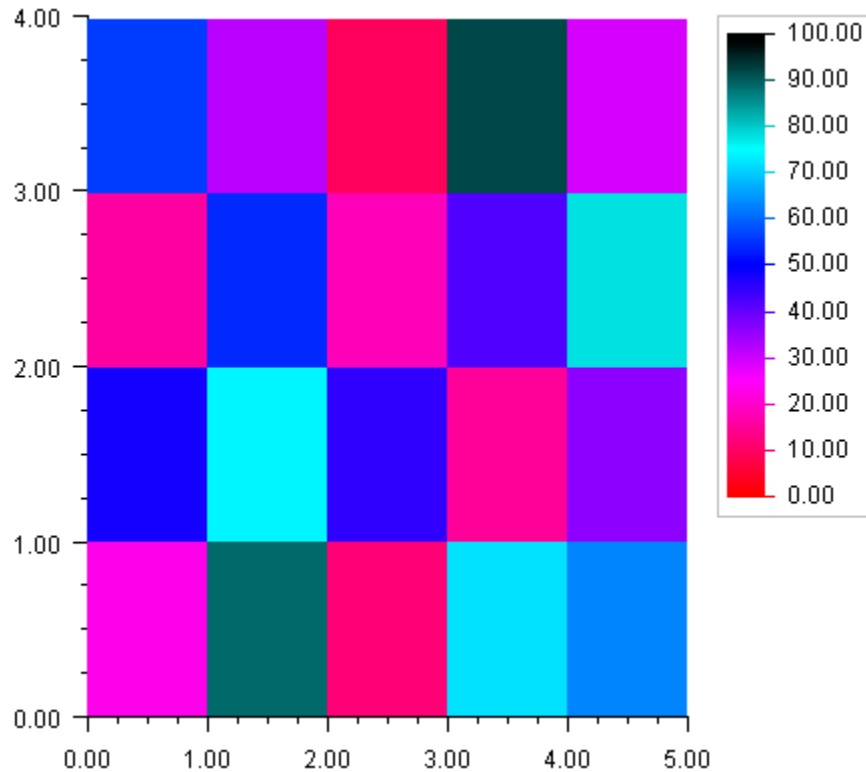
If the data array is m by n then there are m divisions along the x -axis and n divisions along the y -axis.

A [Colormap](#) is a mapping from $[0,1]$ to color values. The blue-red colormap, used in the example below, maps 0 to red and 1 to dark blue and interpolates between these endpoints values. The heatmap maps the minimum data value to the color corresponding to 0 and the highest data value to the color corresponding to 1.

The Heatmap class has a special legend for colormaps. It displays the color values as a gradient labeled with corresponding data values.

Example

In this example a two-dimensional array of data is plotted as a heatmap. The “red-blue” colormap is used. The [HeatmapLegend](#) is enabled by setting its [IsVisible](#) property to true.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
  
public class SampleHeatmap : FrameChart {  
  
    public SampleHeatmap() {  
        Chart chart = this.Chart;  
        AxisXY axis = new AxisXY(chart);  
  
        double xmin = 0.0;  
        double xmax = 5.0;  
        double ymin = 0.0;  
        double ymax = 4.0;  
        double zmin = 0.0;  
        double zmax = 100.0;  
        double[,] data = new double [,] {  
            {23, 48, 16, 56},  
            {89, 74, 54, 32},  
            {12, 45, 18, 9},  
            {72, 15, 42, 92},  
        };  
    }  
}
```

```

        {63, 36, 78, 29}
    };
    Heatmap heatmap = new Heatmap(axis, xmin, xmax, ymin, ymax,
        zmin, zmax, data, Colormap_Fields.BLUE_RED);
    heatmap.HeatmapLegend.IsVisible = true;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleHeatmap());
}
}

```

Treemap

A [Treemap](#) divides a rectangle into subrectangles. The size of each rectangle is determined by an array of data values. The color of each subrectangle is determined by the value of a second data array and a [Colormap](#).

The primary data array is a sorted set of values to map to the subrectangle areas. The placement algorithm is adapted from Bruls, Mark and Huizing, Kees and Wijk, Jarke J. van (2000) *Squarified Treemaps*. In Proceedings of the Joint Eurographics and IEEE TCVG Symposium on Visualization.

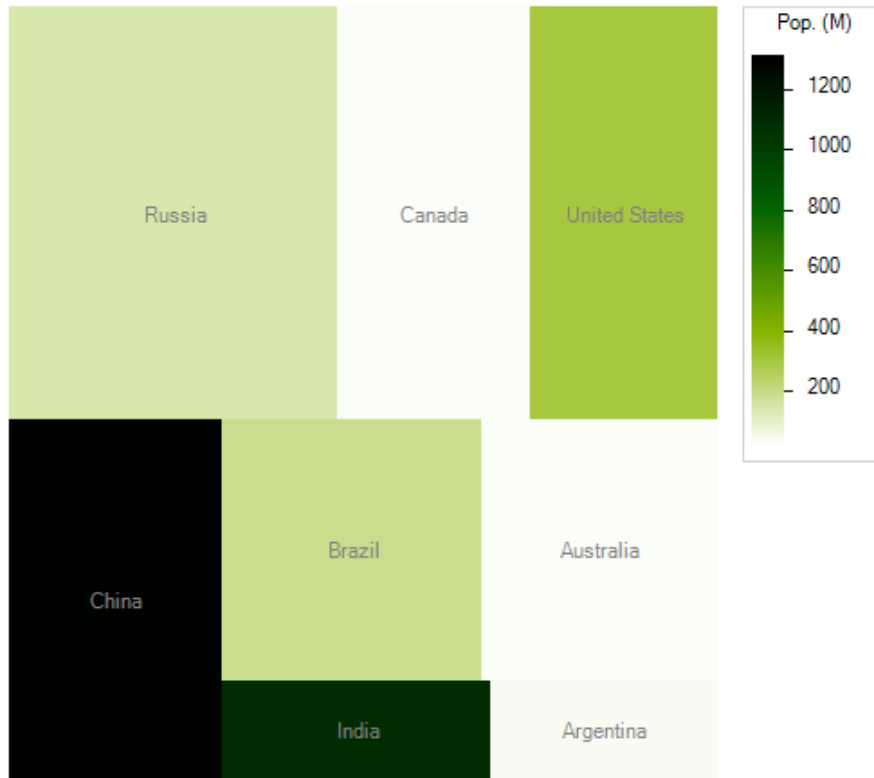
By default, the algorithm fills either rows first or columns first determined by the aspect ratio of the resulting subrectangles. The user may force drawing orientation by using the [Orientation](#) property with [Treemap.OrientationMethod.ColumnFirst](#) or [Treemap.OrientationMethod.RowFirst](#).

A [Colormap](#) is a mapping from [0,1] to color values. The [Treemap](#) maps the minimum value of the second data array to the color corresponding to 0 and the highest value to the color corresponding to 1.

The [TreemapLegend](#) is enabled by setting its [IsVisible](#) property to true.

Example

In this example an array of country data is plotted as a [Treemap](#). The area is proportional to the country's land area while the shading maps to the population. The "green-white-linear" [Colormap](#) is used. The [TreemapLegend](#) is enabled by setting its [IsVisible](#) property to true.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleTreemap : FrameChart {
    public SampleTreemap() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[] areas = {
            6592735, 3855081, 3718691, 3705386,
            3286470, 2967893, 1269338, 1068296};

        double[] population = {
            142.893540, 33.098932, 298.444215, 1313.973713,
            188.078227, 20.264082, 1095.351995, 39.930091};

        string[] names = {
```

```

        "Russia", "Canada", "United States", "China",
        "Brazil", "Australia", "India", "Argentina"};

    Treemap treemap = new Treemap(axis, areas, population,
        Colormap_Fields.GREEN_WHITE_LINEAR);
    treemap.SetTreemapLabels(names);
    treemap.TextColor = Color.Gray;
    treemap.TreemapLegend.IsVisible = true;
    treemap.TreemapLegend.SetTitle("Pop. (M)");
    treemap.TreemapLegend.TextFormat = "0";
    axis.SetViewport(0.05, 0.8, 0.1, 0.95);
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleTreemap());
}
}

```

Histogram

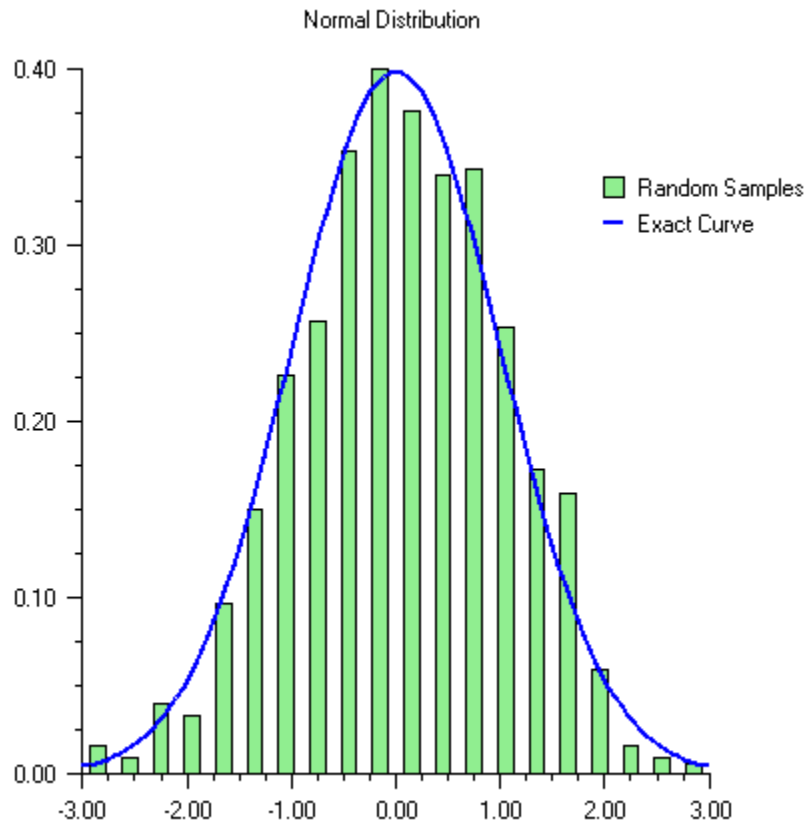
A histogram is a bar chart in which the height of the bars is proportional to the frequencies. A histogram generally uses the same axis style as a scatter plot (i.e. the bars are numbered not labeled.)

In IMSL C# Numerical Library, histograms are drawn using the [Bar](#) class, but its [SetLabels](#) method is not used.

Example

In this example [normally](#) distributed random numbers are generated and placed into 20 uniformly sized bins in the interval [-3,3]. Points outside of this interval are ignored. The bin counts are scaled by the number of samples and the bin width. The scaled bin counts are charted using [Bar](#) chart. The exact normal distribution is implemented as a [ChartFunction](#) and plotted.

The [Legend](#) is displayed by setting the legend node's [IsVisible](#) property to `true` and defining the bar chart's [Title](#) attribute. The Legend is positioned on the chart by setting its [Viewport](#) attribute.



[\(Download Code\)](#)

```

using Imsl.Chart2D;
using System;
using System.Drawing;
using Imsl.Stat;

public class SampleHistogram : FrameChart {

    public SampleHistogram() {
        int nSamples = 1000;
        int nBins = 20;

        // Setup the bins
        double[] bins = new double[nBins];
        double dx = 6.0/nBins;
        double[] x = new double[nBins];
        for (int k = 0; k < x.Length; k++) {
            x[k] = -3.0 + (k+0.5)*dx;
        }

        Imsl.Stat.Random r = new Imsl.Stat.Random(123457);
  
```

```

for (int k = 0; k < nSamples; k++) {
    double t = r.NextNormal();
    int j = (int)Math.Round((t+3.0-0.5*dx)/dx);
    if (j >= 0 && j < nBins) bins[j]++;
}

// Scale the bins
for (int k = 0; k < nBins; k++) {
    bins[k] /= nSamples*dx;
}

// create the chart
Chart chart = this.Chart;
AxisXY axis = new AxisXY(chart);

chart.ChartTitle.SetTitle("Normal Distribution");
chart.Legend.IsVisible = true;
chart.Legend.SetViewport(0.7, 1.0, 0.2, 0.3);
chart.Legend.FillOutlineType = Chart.FILL_TYPE_NONE;

Bar bar = new Bar(axis, x, bins);
bar.BarType = Bar.BAR_TYPE_VERTICAL;
bar.FillColor = Color.LightGreen;
bar.BarWidth = 0.5*dx;
bar.SetTitle("Random Samples");

// plot the expected curve
Data data = new Data(axis, new NormalDist(), -3, 3.0);
data.LineColor = Color.Blue;
data.SetTitle("Exact Curve");
data.LineWidth = 2.0;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleHistogram());
}
}

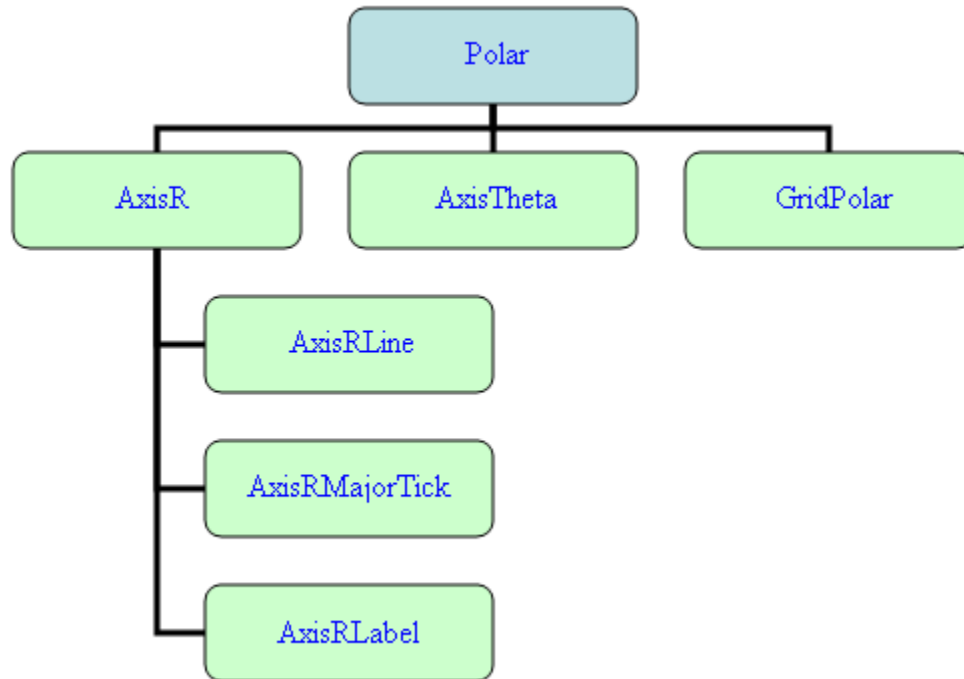
class NormalDist : ChartFunction {
    public double F(double x) {
        return Math.Exp(-0.5*x*x)/Math.Sqrt(2.0*Math.PI);
    }
}
}

```

Polar Plot

The class [Polar](#) is used to plot (r, θ) data, where r is the distance from the origin and θ is the angle from the positive x -axis. [Data](#) node (x, y) values are treated as if they were (r, θ) values.

When a `Polar` node is created, a subtree of other nodes is created. These automatically created nodes are shown in the following diagram.



[AxisR](#) is the r -axis node. This is drawn along the positive x -axis. This node has three subnodes: [AxisRLine](#) for the actual line, [AxisRMajorTick](#) for the tick marks along the line and [AxisRLabel](#) for the tick mark labels.

The drawing of the [AxisRLine](#) and the [AxisRMajorTick](#) is controlled by the [Line Attributes](#). The drawing of the [AxisRLabel](#) is controlled by the [Text Attributes](#).

The `Window` attribute in [AxisR](#) specifies the length of the r -axis. Since the r -axis range is $[0, rmax]$, the `Window` attribute for this node is the $rmax$ value. Autoscaling is used to automatically determine $rmax$ from the data. Autoscaling can be turned off. See [Autoscale](#) for more details.

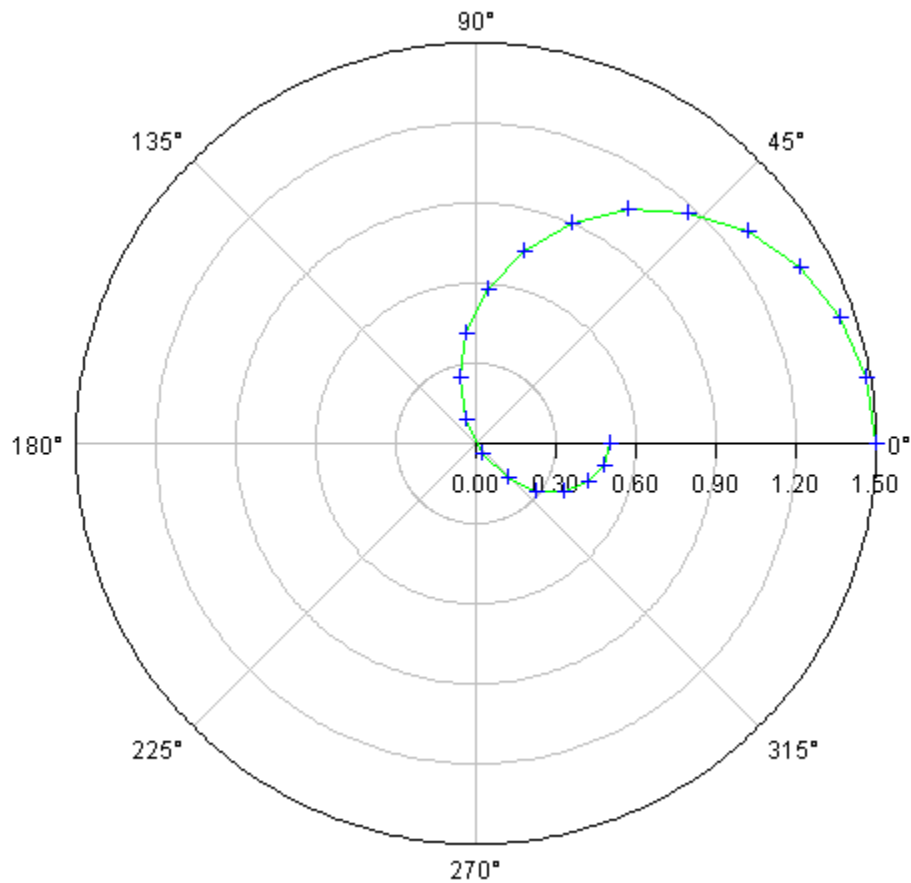
[AxisTheta](#) is the θ -axis node. It is drawn as a circle around the plot. The drawing of the circle itself is controlled by the line attributes. The drawing of the axis labels is controlled by the text attributes.

The `Window` attribute in the [AxisTheta](#) node contains the angular range, in radians. Its default value is $[0, 2\pi]$. The `Window` attribute can be explicitly set to change the range, but autoscaling is not available to determine the angular range.

[GridPolar](#) is the plot grid. It consists of both radial and circular lines. The drawing of these lines is controlled by the line attributes. By default, these lines are drawn and are light gray.

Example

The function $r = 0.5 + \cos(q)$, for $0 \leq q \leq p$ is plotted.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;
using System;

public class SamplePolar : FrameChart {

    public SamplePolar() {
        Chart chart = this.Chart;
        Polar axis = new Polar(chart);

        double[] r = new double[20];
        double[] theta = new double[r.Length];
        for (int k = 0; k < r.Length; k++) {
            theta[k] = Math.PI*k/(r.Length-1);
            r[k] = 0.5 + Math.Cos(theta[k]);
        }
        Data data = new Data(axis, r, theta);
        data.DataType = Data.DATA_TYPE_MARKER | Data.DATA_TYPE_LINE;
        data.LineColor = Color.Lime;
    }
}
```

```
        data.MarkerColor = Color.Blue;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SamplePolar());
    }
}
```

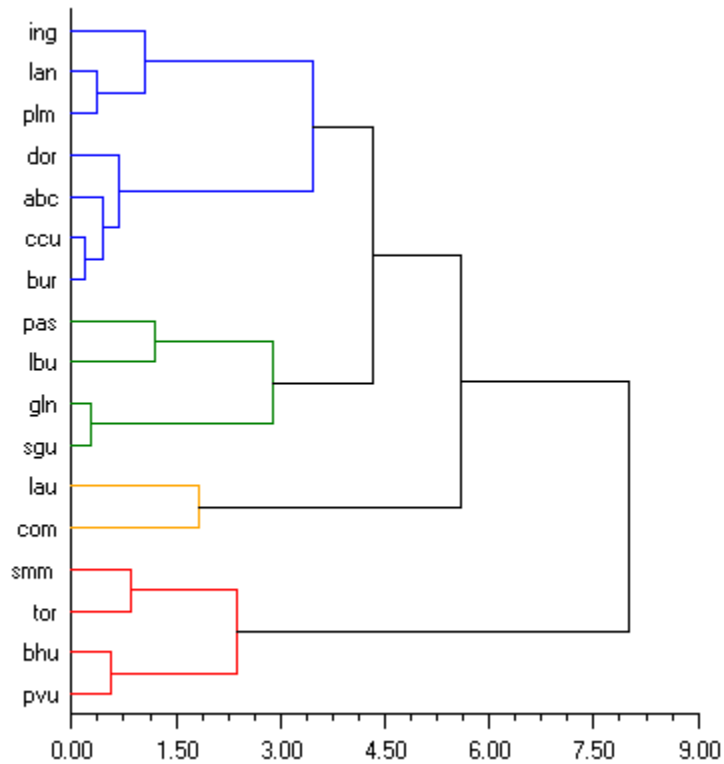
Dendrogram Chart

A [Dendrogram](#) chart is a graphical way to display results from hierarchical cluster analysis. This section describes the construction of a dendrogram chart.

Example

The data for this example is grouped into clusters using the [Dissimilarities](#) and [ClusterHierarchical](#) classes. A Dendrogram node is then created as a child of an axis node. The Dendrogram constructor requires input values from the ClusterHierarchical object.

The [SetLabels](#) and [SetLineColors](#) methods are used to customize the look of the chart. Labels are provided in a String array in the order of the input data and sorted by the Dendrogram object to match the output order. Clusters are grouped by color based on the number of elements in the array passed to the SetLineColors method.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Stat;
using System.Drawing;

public class SampleDendrogram : FrameChart {

    public SampleDendrogram() {
        /*
        1998 test data from 17 school districts in Los Angeles County.

        The variables were:
        lep - Proportion of LEP students to total tested
        read - The Reading Scaled Score for 5th Grade
        math - The Math Scaled Score for 5th Grade
        lang - The Language Scaled Score for 5th Grade

        The districts were:
        lau - Los Angeles
        ccu - Culver City
        bhu - Beverly Hills
        ing - Inglewood
        com - Compton
        smm - Santa Monica Malibu
        */
    }
}
```

```

bur - Burbank
gln - Glendale
pvu - Palos Verdes
sgu - San Gabriel
abc - Artesia, Bloomfield, and Carmenita
pas - Pasadena
lan - Lancaster
plm - Palmdale
tor - Torrance
dow - Downey
lbu - Long Beach

```

```

input lep read math lang str3 district
.38 626.5 601.3 605.3 lau
.18 654.0 647.1 641.8 ccu
.07 677.2 676.5 670.5 bhv
.09 639.9 640.3 636.0 ing
.19 614.7 617.3 606.2 com
.12 670.2 666.0 659.3 smm
.20 651.1 645.2 643.4 bur
.41 645.4 645.8 644.8 gln
.07 683.5 682.9 674.3 pvu
.39 648.6 647.8 643.1 sgu
.21 650.4 650.8 643.9 abc
.24 637.0 636.9 626.5 pas
.09 641.1 628.8 629.4 lan
.12 638.0 627.7 628.6 plm
.11 661.4 659.0 651.8 tor
.22 646.4 646.2 647.0 dow
.33 634.1 632.0 627.8 lbu
*/

```

```

double[,] data = {
    { .38, 626.5, 601.3, 605.3 },
    { .18, 654.0, 647.1, 641.8 },
    { .07, 677.2, 676.5, 670.5 },
    { .09, 639.9, 640.3, 636.0 },
    { .19, 614.7, 617.3, 606.2 },
    { .12, 670.2, 666.0, 659.3 },
    { .20, 651.1, 645.2, 643.4 },
    { .41, 645.4, 645.8, 644.8 },
    { .07, 683.5, 682.9, 674.3 },
    { .39, 648.6, 647.8, 643.1 },
    { .21, 650.4, 650.8, 643.9 },
    { .24, 637.0, 636.9, 626.5 },
    { .09, 641.1, 628.8, 629.4 },
    { .12, 638.0, 627.7, 628.6 },
    { .11, 661.4, 659.0, 651.8 },
    { .22, 646.4, 646.2, 647.0 },
    { .33, 634.1, 632.0, 627.8 } };

```

```

string[] lab = { "lau", "ccu", "bhv", "ing", "com", "smm",
    "bur", "gln", "pvu", "sgu", "abc", "pas",
    "lan", "plm", "tor", "dor", "lbu" };

```

```

// 3rd arg in Dissimilarities gives different results for 0,1,2
Dissimilarities dist = new Dissimilarities(data, 0, 1, 1);
ClusterHierarchical clink =
    new ClusterHierarchical(dist.DistanceMatrix, 4, 0);

int nClusters = 4;
int[] iclus = clink.GetClusterMembership(nClusters);
int[] nclus = clink.GetObsPerCluster(nClusters);

Chart chart = this.Chart;
AxisXY axis = new AxisXY(chart);

// use either method below to create the chart
Dendrogram dc =
    new Dendrogram(axis, clink,
        Data.DENDROGRAM_TYPE_HORIZONTAL);
/*
    new Dendrogram(axis, clink.getClusterLevel(),
        clink.getClusterLeftSons(), clink.getClusterRightSons(),
        Data.DENDROGRAM_TYPE_HORIZONTAL);
*/
dc.SetLabels(lab);
dc.SetLineColors(new Color[]{Color.Blue, Color.Green,
    Color.Red, Color.Orange});
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleDendrogram());
}
}

```


Chapter 3: Quality Control and Improvement Charts

Introduction

Quality improvement charts have a variety of uses. In this library the charts are organized into three broad groups: Shewhart control charts, other control charts and process improvement charts. The Shewhart control charts were originally described by the statistician Dr. Walter A. Shewhart (1931). Since this early work, other charts have been developed for engineering and management analysis of processes. In the 1980s customized charts were developed for other retrospective analysis of quality management data.

This chapter discusses these IMSL C# Numerical Library Quality Control Charts: IMSL C# Numerical Library provides these Quality Control Charts:

- [“ShewhartControlChart and ControlLimit”](#) on page 67
- [“XbarS and SChart”](#) on page 70
- [“XbarR and RChart”](#) on page 78
- [“XmR”](#) on page 82
- [“PChart”](#) on page 84
- [“NpChart”](#) on page 87
- [“CChart”](#) on page 89
- [“UChart”](#) on page 92
- [“EWMA”](#) on page 96
- [“CuSum”](#) on page 98
- [“CuSumStatus”](#) on page 100
- [“Pareto Chart”](#) on page 102
- [“Cumulative Probability”](#) on page 104

Shewhart Charts

While working for Western Electric in the 1920s, Dr. Shewhart developed a general, practical approach to statistical monitoring of manufacturing processes. He advised managers on

implementing these within Western Electric and later published his work in Shewhart (Montgomery, 1931). All Shewhart control charts share several characteristics in common. First, the horizontal axis represents time or lot sequence, but they all have different vertical axes, depending upon the chart time.

Next, all Shewhart control charts have a center line that is drawn parallel to the time axis. This typically represents the mean of the process, but the value of the process mean can vary depending upon which data are first used to design the chart. In some cases it will be the mean of the data plotted, in others it could be the mean calculated from a much larger number of measurements on the historical operation of the process.

Lastly, all Shewhart control charts have lines drawn to represent either the upper or lower control limits. In most cases both control lines are present, in others where the data have a natural bound, such as zero, only one of these control limits might be drawn.

Shewhart control charts are also broadly classified into two groups: *variable* and *attribute* data charts. *Variable control charts* are used when the quality of interest is a continuous variable, such as the diameter of a valve. If w is a continuous measure of a quality of interest, with mean μ_w and within-sample standard deviation σ_w , then the center line is at μ_w and the upper and lower controls limits are at $\mu_w \pm k\sigma_w$. Typically $k = 3$ and the charts are called 3-sigma control charts.

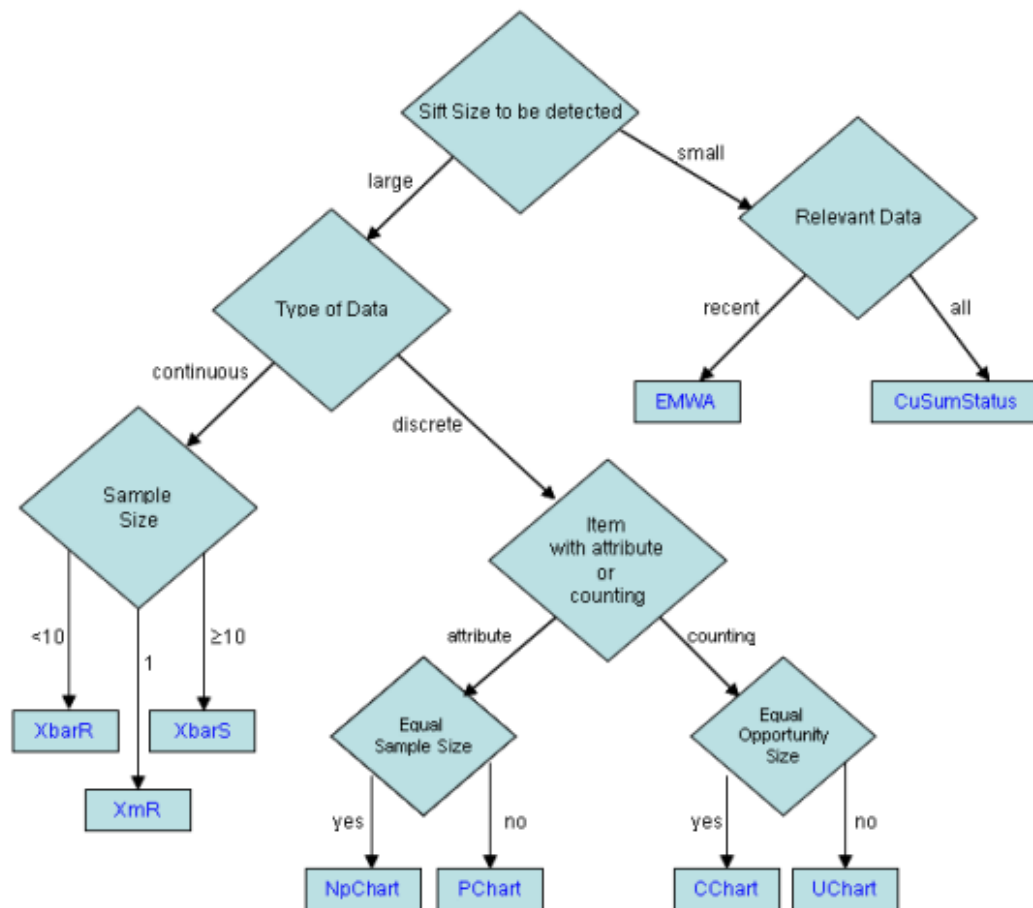
Attribute control charts are used when qualities, not quantities are measured. For example, items may be characterized as conforming or nonconforming to a specification. Items may also be characterized as defective or nondefective. Examples of attributes include the number of failures in a manufacturing run or the number of defects on a computer chip wafer.

When the number of defective or nondefective items are plotted then a [PChart](#) or an [NpChart](#) are generally used to describe the non-conformity data. The [NpChart](#) is used to plot the number of defects when all of the sample sizes are equal, and the [PChart](#) is used when the sample sizes are unequal.

If a single item can have multiple defects then a [CChart](#) or [UChart](#) is used, depending upon whether the area inspected for defect is consistent or varying. An example of multiple defects per item would be the count of the number of scratches on mirrors. If all samples have an equal opportunity for defects use [CChart](#), otherwise use [UChart](#). So to monitor the number of scratches on mirrors use [CChart](#) when all mirrors being made are the same size and use [UChart](#) for mirrors being made that are sized differently.

In IMSL C# Numerical Library the [ShewhartControlChart](#) class is the base of a number of classes; it is not usually used by itself. Most of the charts in this chapter extend [ShewhartControlChart](#).

The following diagram can be used to determine the appropriate control chart to be used in a given situation.



Variable Control Charts:

- [XbarR](#) estimates μ_w and σ_w using the ranges of the samples. It is best used when the sample size of a continuous variable is between 2 and 10.
- [RChart](#) plots the sample ranges. It is typically used in conjunction with [XbarR](#).
- [XbarS](#) estimates μ_w and σ_w using the means and standard deviations of the samples. It is best used when the sample size of a continuous variable is at least 10.
- [SChart](#) plots the sample standard deviations. It is typically used in conjunction with [XbarS](#).
- [XmR](#) is a moving range chart. It is used when the sample size of a continuous variable is one.

- [EWMA](#) (Exponentially Weighted Moving-Average) plots weighted moving average values. It is used when the sample size of a continuous variable is one.

Attribute Control Charts:

- [NpChart](#) plots the number of defects. It is used when defects are not rare.
- [PChart](#) plots the rate of defects. It is used when defects are not rare.
- [CChart](#) plots the defect count. It is used when defects are rare.
- [UChart](#) plots the rate of defects. It is used when defects are rare.

Other Control Charts

CuSum and CuSumStatus

The [CuSum](#) and [CuSumStatus](#) charts are more efficient than [Shewhart](#) charts at detecting small shifts in the process mean because the plot represents the moving average of the cumulative differences between the process and its target (centerline).

Cumulative Probability

Cumulative probability charts are used if the defect rate is so small that there will be long runs when the number of defects is zero.

Process Improvement Charts

Pareto Chart

[Pareto](#) charts are used to analyze the root cause of process defects. They are based on the “Pareto Principal” which claims that 80% of the defects are caused by only 20% of the defect categories.

[Pareto](#) charts resemble bar charts but are different. In a [Pareto](#) chart, the defect category with the largest number of defects always appears as the first and tallest bar on the chart. The other bars represent the remaining defect categories in descending order of magnitude.

ShewhartControlChart and ControlLimit

The [ShewhartControlChart](#) class is primarily used as the base class of other control chart classes. It provides the common functionality for the control charts.

For example, the default IMSL.NET control charts include a center line and an upper and lower control limit at plus or minus three standard deviations from the center line. The Western Electric Company Rules (or WECO) are control limits at plus or minus one, two, and three standard deviations from the mean. They can be added using the method [AddWecoLimits](#) in the [ShewhartControlChart](#) class.

The `ShewhartControlChart` uses the `ControlLimit` class for the upper and lower control limits and for the center line. Additional control limits, such as the WECO limits, can be added to a `ShewhartControlChart`. The line attributes can be used with `ControlLimit` to modify the drawing of each control limit.

The `ShewhartControlChart` class can be used directly when the statistics are computed by the user. In this example, data from Montgomery, Douglas C., [Introduction to Statistical Quality Control](#), 4th Ed.,, 2001, New York: John Wiley and Sons, p. 406 is plotted. The code explicitly sets the lower control limit to 7 and the upper control limit to 13.

Further citations throughout this chapter for data plotted from Montgomery appear as parenthetical citations, e.g. (Montgomery 406).

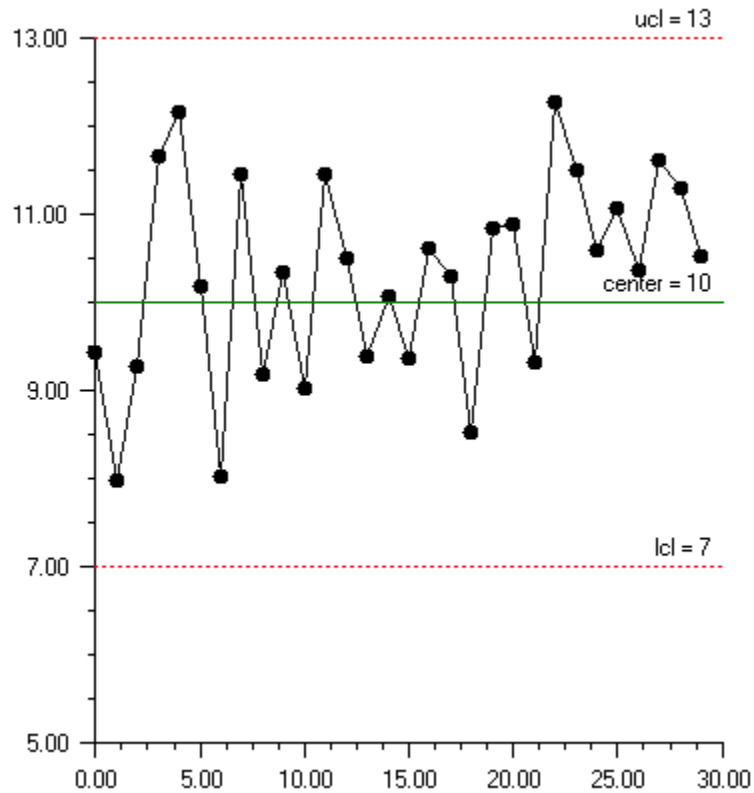
Control Limit Customization

Control Limits and center lines can be added using the `ControlLimit.SetValue` methods; `AddCenterLine().SetValue(int)` (see `AddCenterLine()`), `AddUpperControlLimit().SetValue(int)` (see `AddUpperControlLimit()`) and `AddLowerControlLimit().SetValue(int)` (see `AddLowerControlLimit()`). It is foreseeable that the default appearance might not be optimal for every application. In particular moving components or removing the `ControlLimit` objects can be accomplished.

Before modifying a `ControlLimit` title it is important to realize the `ControlLimit` title text is justified in the lower right corner of a `Text` object (`TEXT_X_RIGHT` | `TEXT_Y_BOTTOM`). With this in mind, formatted strings may be used to alter their appearance. For example, to retain the `ControlLimit` line but eliminate the title, get the `ControlLimit` and `set the title` to an empty string (i.e. `UpperControlLimit.SetTitle("")`). In addition, the following can be used to move the title closer to the y-axis (note that repeated, leading, and trailing new lines `"\n"` and spaces are ignored):

```
xbars.UpperControlLimit.SetTitle("ucl=15\t\t\t");
```

After being added, it may be the case that a `ControlLimit` should be removed. This is accomplished with the object's inherited `Remove()` method.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleShewhart : FrameChart {
    static double[] data = {
        9.45, 7.99, 9.29, 11.66, 12.16, 10.18, 8.04, 11.46,
        9.20, 10.34, 9.03, 11.47, 10.51, 9.40, 10.08, 9.37,
        10.62, 10.31, 8.52, 10.84, 10.90, 9.33, 12.29, 11.50,
        10.60, 11.08, 10.38, 11.62, 11.31, 10.52
    };
};

public SampleShewhart() {
    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);
    ShewhartControlChart xbars = new ShewhartControlChart(axis);
    xbars.SetData(data);
    xbars.AddLowerControlLimit().SetValue(7);
    xbars.AddCenterLine().SetValue(10);
    xbars.AddUpperControlLimit().SetValue(13);
}
}
```

```

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleShewhart());
}
}

```

XbarS and SChart

The [XbarS](#) class plots the mean of each sample as well as control limits computed using the mean of the in-sample standard deviations. The positions of the control limits are determined by the equations

$$UCL = \bar{\bar{x}} + 3 \frac{\bar{s}}{c_4 \sqrt{n}}$$

$$Centerline = \bar{\bar{x}}$$

$$LCL = \bar{\bar{x}} - 3 \frac{\bar{s}}{c_4 \sqrt{n}}$$

where $\bar{\bar{x}}$ is the grand mean, the average of all the observations.

The factor of three in the above equations can be changed by setting the chart attribute [ControlLimit](#). The attribute applies similarly to all of the control charts.

XbarS Example

The process of forging piston rings for automobile engines was monitored. The inside diameters of 25 samples, each containing 5 piston rings, were measured. The center line is at 74.001, the average diameter of all of the measured piston rings. The upper and lower control limits are determined by the average of the standard deviations of the 25 samples of 5 rings (Montgomery 215).

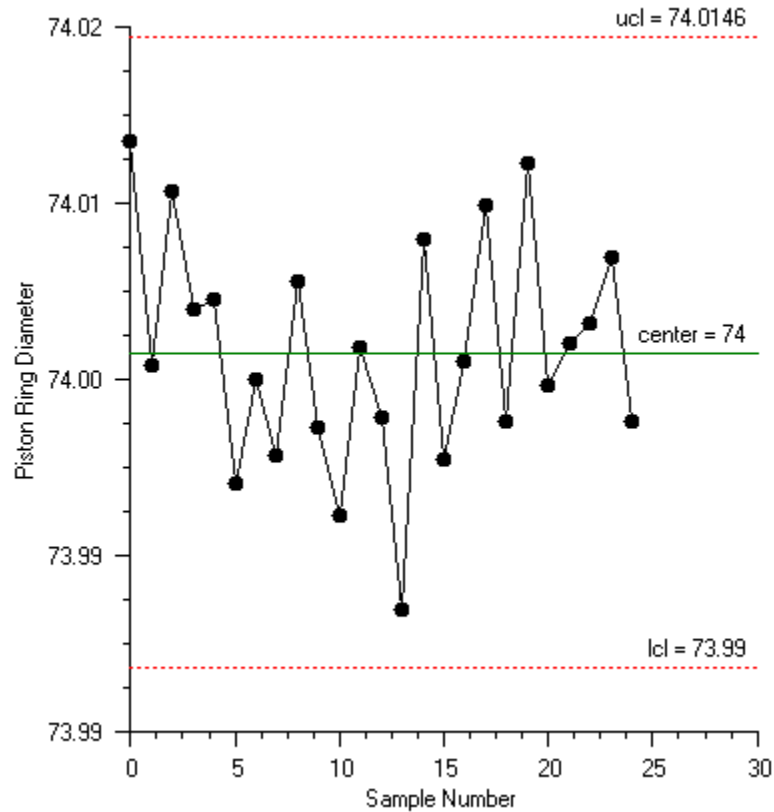
The [SChart](#) plots the in-sample standard deviations of the observations as well as control limits computed using

$$UCL = \bar{s} + 3 \frac{\bar{s}}{c_4} \sqrt{1 - c_4^2}$$

$$Centerline = \bar{s}$$

$$LCL = \bar{s} - 3 \frac{\bar{s}}{c_4} \sqrt{1 - c_4^2}$$

The factor c_4 is such that \bar{s} / c_4 is an unbiased estimator of standard deviation.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleXbarS : FrameChart {
    static double[][] diameter = {
        new double[] {74.03, 74.002, 74.019, 73.992, 74.008},
        new double[] {73.995, 73.992, 74.001, 74.011, 74.004},
        new double[] {73.988, 74.024, 74.021, 74.005, 74.002},
        new double[] {74.002, 73.996, 73.993, 74.015, 74.009},
        new double[] {73.992, 74.007, 74.015, 73.989, 74.014},
        new double[] {74.009, 73.994, 73.997, 73.985, 73.993},
        new double[] {73.995, 74.006, 73.994, 74, 74.005},
    };
}
```

```

        new double[] {73.985, 74.003, 73.993, 74.015, 73.988},
        new double[] {74.008, 73.995, 74.009, 74.005, 74.004},
        new double[] {73.998, 74, 73.99, 74.007, 73.995},
        new double[] {73.994, 73.998, 73.994, 73.995, 73.99},
        new double[] {74.004, 74, 74.007, 74, 73.996},
        new double[] {73.983, 74.002, 73.998, 73.997, 74.012},
        new double[] {74.006, 73.967, 73.994, 74, 73.984},
        new double[] {74.012, 74.014, 73.998, 73.999, 74.007},
        new double[] {74, 73.984, 74.005, 73.998, 73.996},
        new double[] {73.994, 74.012, 73.986, 74.005, 74.007},
        new double[] {74.006, 74.01, 74.018, 74.003, 74},
        new double[] {73.984, 74.002, 74.003, 74.005, 73.997},
        new double[] {74, 74.01, 74.013, 74.02, 74.003},
        new double[] {73.982, 74.001, 74.015, 74.005, 73.996},
        new double[] {74.004, 73.999, 73.99, 74.006, 74.009},
        new double[] {74.01, 73.989, 73.99, 74.009, 74.014},
        new double[] {74.015, 74.008, 73.993, 74, 74.01},
        new double[] {73.982, 73.984, 73.995, 74.017, 74.013}
    };

    public SampleXbarS() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        XbarS xbars = new XbarS(axis, diameter);

        xbars.UpperControlLimit.SetTitle("ucl = {0:0.0000}");

        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("Piston Ring Diameter");
        axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
        axis.AxisY.SetWindow(73.985, 74.015);
    }

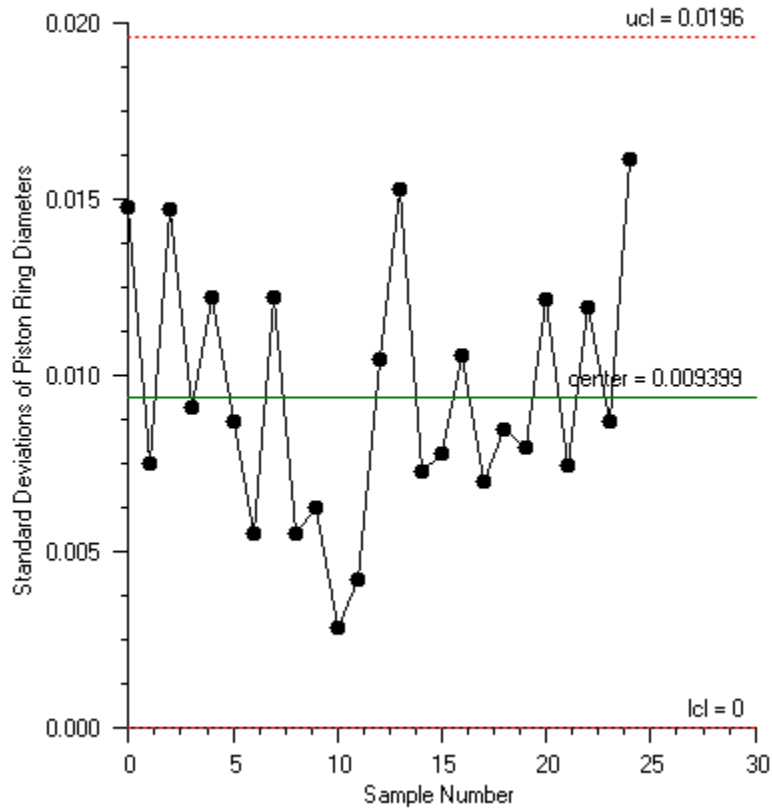
    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleXbarS());
    }
}

```

SChart Example

This example uses the same piston ring data as was used in the [XbarS example](#) on page 70, but now the standard deviations of the samples are plotted. The center line is at 0.009, the average of the sample standard deviations.

Often the [XbarS](#) and [SChart](#) are plotted together. The `xbarS` class contains the static method [CreateCharts](#), which creates this pair of plots on a single chart.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;
```

```
public class SampleSChart : FrameChart {
    static double[][] diameter = {
        new double[] {74.03, 74.002, 74.019, 73.992, 74.008},
        new double[] {73.995, 73.992, 74.001, 74.011, 74.004},
        new double[] {73.988, 74.024, 74.021, 74.005, 74.002},
        new double[] {74.002, 73.996, 73.993, 74.015, 74.009},
        new double[] {73.992, 74.007, 74.015, 73.989, 74.014},
        new double[] {74.009, 73.994, 73.997, 73.985, 73.993},
        new double[] {73.995, 74.006, 73.994, 74, 74.005},
        new double[] {73.985, 74.003, 73.993, 74.015, 73.988},
        new double[] {74.008, 73.995, 74.009, 74.005, 74.004},
        new double[] {73.998, 74, 73.99, 74.007, 73.995},
        new double[] {73.994, 73.998, 73.994, 73.995, 73.99},
        new double[] {74.004, 74, 74.007, 74, 73.996},
        new double[] {73.983, 74.002, 73.998, 73.997, 74.012},
        new double[] {74.006, 73.967, 73.994, 74, 73.984},
        new double[] {74.012, 74.014, 73.998, 73.999, 74.007},
    };
}
```

```

        new double[] {74, 73.984, 74.005, 73.998, 73.996},
        new double[] {73.994, 74.012, 73.986, 74.005, 74.007},
        new double[] {74.006, 74.01, 74.018, 74.003, 74},
        new double[] {73.984, 74.002, 74.003, 74.005, 73.997},
        new double[] {74, 74.01, 74.013, 74.02, 74.003},
        new double[] {73.982, 74.001, 74.015, 74.005, 73.996},
        new double[] {74.004, 73.999, 73.99, 74.006, 74.009},
        new double[] {74.01, 73.989, 73.99, 74.009, 74.014},
        new double[] {74.015, 74.008, 73.993, 74, 74.01},
        new double[] {73.982, 73.984, 73.995, 74.017, 74.013}
    };

    public SampleSChart() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        SChart schart = new SChart(axis, diameter);

        schart.UpperControlLimit.SetTitle("ucl = {0:0.0000}");

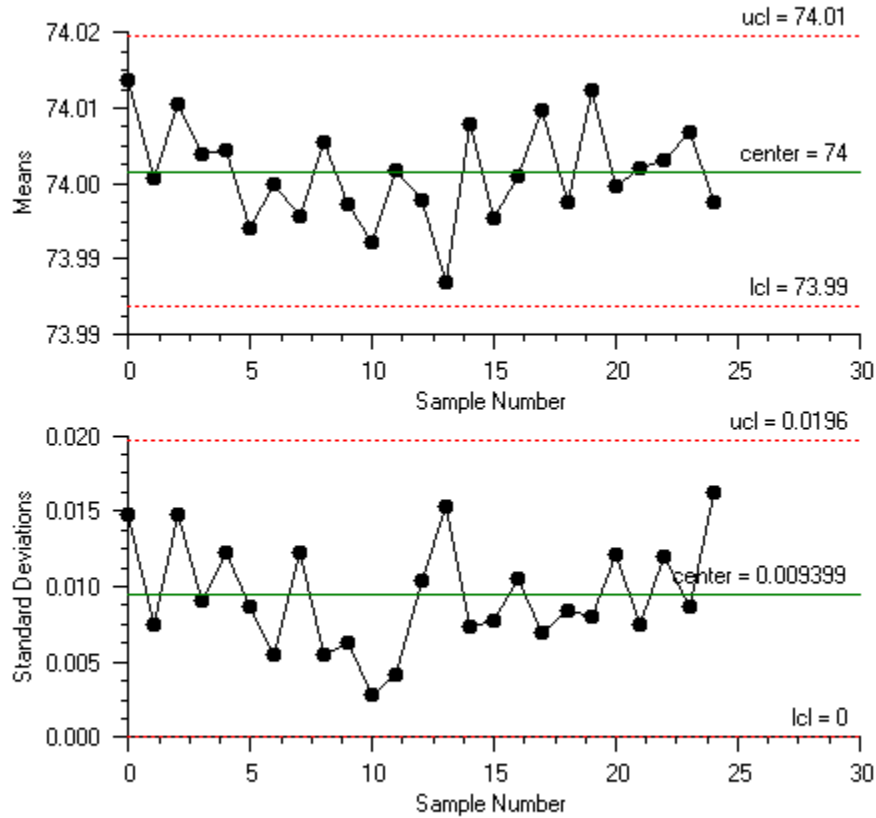
        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("Standard Deviations of " +
            "Piston Ring Diameters");
        axis.AxisY.AxisLabel.TextFormat = "0.000";
        axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
        axis.AxisY.SetWindow(0.0, 0.02);
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleSChart());
    }
}

```

XbarSCombo Example

This example combines the charts in the XbarS and SChart examples. The [Viewport](#) attribute of each is set so that they can appear on the same chart.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;
```

```
public class SampleXbarSCombo : FrameChart {
    static double[][] diameter = {
        new double[] {74.03, 74.002, 74.019, 73.992, 74.008},
        new double[] {73.995, 73.992, 74.001, 74.011, 74.004},
        new double[] {73.988, 74.024, 74.021, 74.005, 74.002},
        new double[] {74.002, 73.996, 73.993, 74.015, 74.009},
        new double[] {73.992, 74.007, 74.015, 73.989, 74.014},
        new double[] {74.009, 73.994, 73.997, 73.985, 73.993},
        new double[] {73.995, 74.006, 73.994, 74, 74.005},
        new double[] {73.985, 74.003, 73.993, 74.015, 73.988},
        new double[] {74.008, 73.995, 74.009, 74.005, 74.004},
        new double[] {73.998, 74, 73.99, 74.007, 73.995},
        new double[] {73.994, 73.998, 73.994, 73.995, 73.99},
    };
}
```

```

        new double[] {74.004, 74, 74.007, 74, 73.996},
        new double[] {73.983, 74.002, 73.998, 73.997, 74.012},
        new double[] {74.006, 73.967, 73.994, 74, 73.984},
        new double[] {74.012, 74.014, 73.998, 73.999, 74.007},
        new double[] {74, 73.984, 74.005, 73.998, 73.996},
        new double[] {73.994, 74.012, 73.986, 74.005, 74.007},
        new double[] {74.006, 74.01, 74.018, 74.003, 74},
        new double[] {73.984, 74.002, 74.003, 74.005, 73.997},
        new double[] {74, 74.01, 74.013, 74.02, 74.003},
        new double[] {73.982, 74.001, 74.015, 74.005, 73.996},
        new double[] {74.004, 73.999, 73.99, 74.006, 74.009},
        new double[] {74.01, 73.989, 73.99, 74.009, 74.014},
        new double[] {74.015, 74.008, 73.993, 74, 74.01},
        new double[] {73.982, 73.984, 73.995, 74.017, 74.013}
    };

    public SampleXbarSCombo() {
        Chart chart = this.Chart;
        ShewhartControlChart[] charts = XbarS.CreateCharts(chart, diameter);
        AxisXY axis = (AxisXY)(charts[0].Axis);
        axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
        axis.AxisY.SetWindow(73.985, 74.015);

        axis = (AxisXY)(charts[1].Axis);
        axis.AxisY.AxisLabel.TextFormat = "0.000";
        axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
        axis.AxisY.SetWindow(0.0, 0.02);
        ((SChart)charts[1]).UpperControlLimit.SetTitle("ucl = {0:0.0000}");
    }

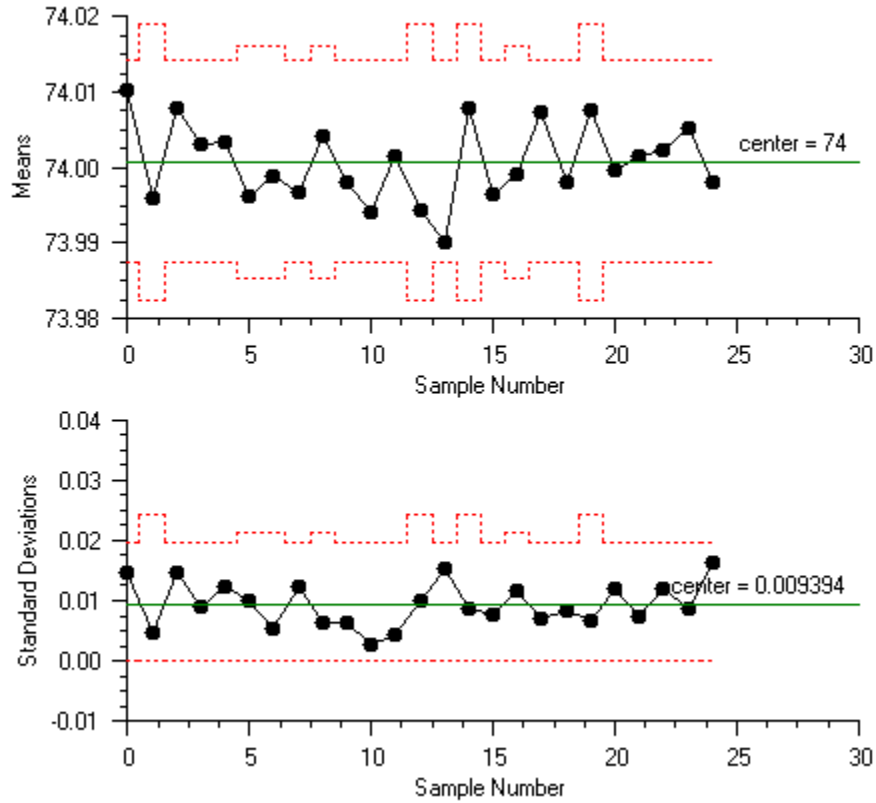
    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleXbarSCombo());
    }
}

```

XbarSUnequal Example

The example again uses the piston ring data, but now the sample size is not uniform. The upper and lower control limits are now stair-step lines. The control limits are farther apart for smaller samples.

It is also possible to plot just the [xbarS](#) or [SChart](#) with unequal sample sizes.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;
```

```
public class SampleXbarSUnequal : FrameChart {
    static double[][] diameter = {
        new double[] {74.03, 74.002, 74.019, 73.992, 74.008},
        new double[] {73.995, 73.992, 74.001},
        new double[] {73.988, 74.024, 74.021, 74.005, 74.002},
        new double[] {74.002, 73.996, 73.993, 74.015, 74.009},
        new double[] {73.992, 74.007, 74.015, 73.989, 74.014},
        new double[] {74.009, 73.994, 73.997, 73.985},
        new double[] {73.995, 74.006, 73.994, 74},
        new double[] {73.985, 74.003, 73.993, 74.015, 73.988},
        new double[] {74.008, 73.995, 74.009, 74.005},
        new double[] {73.998, 74, 73.99, 74.007, 73.995},
        new double[] {73.994, 73.998, 73.994, 73.995, 73.99},
        new double[] {74.004, 74, 74.007, 74, 73.996},
        new double[] {73.983, 74.002, 73.998},
        new double[] {74.006, 73.967, 73.994, 74, 73.984},
    };
}
```

```

    new double[] {74.012, 74.014, 73.998},
    new double[] {74, 73.984, 74.005, 73.998, 73.996},
    new double[] {73.994, 74.012, 73.986, 74.005},
    new double[] {74.006, 74.01, 74.018, 74.003, 74},
    new double[] {73.984, 74.002, 74.003, 74.005, 73.997},
    new double[] {74, 74.01, 74.013},
    new double[] {73.982, 74.001, 74.015, 74.005, 73.996},
    new double[] {74.004, 73.999, 73.99, 74.006, 74.009},
    new double[] {74.01, 73.989, 73.99, 74.009, 74.014},
    new double[] {74.015, 74.008, 73.993, 74, 74.01},
    new double[] {73.982, 73.984, 73.995, 74.017, 74.013}
};

public SampleXbarSUnequal() {
    Chart chart = this.Chart;
    ShewhartControlChart[] charts = XbarS.CreateCharts(
        chart, diameter);
    AxisXY axis = (AxisXY)(charts[0].Axis);
    axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
    axis.AxisY.SetWindow(73.980, 74.020);
    ((SChart)charts[1]).UpperControlLimit.SetTitle(
        "ucl = {0:0.0000}");
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(
        new SampleXbarSUnequal());
}
}

```

XbarR and RChart

If the sample sizes are small, say less than 10, then the in-sample ranges can be used instead of the in-sample standard deviations. The [XbarR](#) class plots the mean of each sample as well as control limits computed using the mean of the in-sample ranges. The positions of the control limits are determined by the equations

$$UCL = \bar{\bar{x}} + \frac{3}{d_2\sqrt{n}} \bar{R}$$

$$Centerline = \bar{\bar{x}}$$

$$LCL = \bar{\bar{x}} - \frac{3}{d_2\sqrt{n}} \bar{R}$$

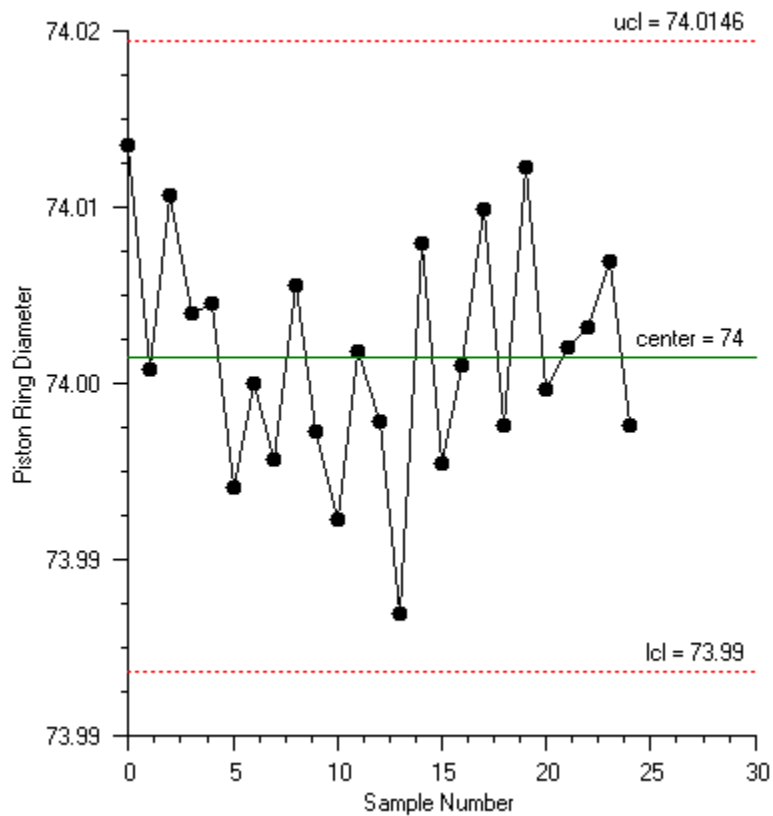
where $\bar{\bar{x}}$ is the grand mean (the average of all observations), and d_2 is the mean of the distribution of the ranges of n samples from the normal distribution with mean of zero and standard deviation of one. The standard deviation of this distribution is d_3 . Therefore

$$\frac{d_3}{d_2} \bar{R}$$

is an estimator of the standard deviation of the ranges.

XbarR Example

This example creates an [XbarR](#) chart using the same piston ring data previously used for the [XbarS example](#). Here the in-sample ranges are used to compute the control limits, rather than the in-sample standard deviations (Montgomery 215).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
```

```

using Imsl.Chart2D.QC;

public class SampleXbarR : FrameChart {
    static double[][] diameter = {
        new double[] {74.03, 74.002, 74.019, 73.992, 74.008},
        new double[] {73.995, 73.992, 74.001, 74.011, 74.004},
        new double[] {73.988, 74.024, 74.021, 74.005, 74.002},
        new double[] {74.002, 73.996, 73.993, 74.015, 74.009},
        new double[] {73.992, 74.007, 74.015, 73.989, 74.014},
        new double[] {74.009, 73.994, 73.997, 73.985, 73.993},
        new double[] {73.995, 74.006, 73.994, 74, 74.005},
        new double[] {73.985, 74.003, 73.993, 74.015, 73.988},
        new double[] {74.008, 73.995, 74.009, 74.005, 74.004},
        new double[] {73.998, 74, 73.99, 74.007, 73.995},
        new double[] {73.994, 73.998, 73.994, 73.995, 73.99},
        new double[] {74.004, 74, 74.007, 74, 73.996},
        new double[] {73.983, 74.002, 73.998, 73.997, 74.012},
        new double[] {74.006, 73.967, 73.994, 74, 73.984},
        new double[] {74.012, 74.014, 73.998, 73.999, 74.007},
        new double[] {74, 73.984, 74.005, 73.998, 73.996},
        new double[] {73.994, 74.012, 73.986, 74.005, 74.007},
        new double[] {74.006, 74.01, 74.018, 74.003, 74},
        new double[] {73.984, 74.002, 74.003, 74.005, 73.997},
        new double[] {74, 74.01, 74.013, 74.02, 74.003},
        new double[] {73.982, 74.001, 74.015, 74.005, 73.996},
        new double[] {74.004, 73.999, 73.99, 74.006, 74.009},
        new double[] {74.01, 73.989, 73.99, 74.009, 74.014},
        new double[] {74.015, 74.008, 73.993, 74, 74.01},
        new double[] {73.982, 73.984, 73.995, 74.017, 74.013}
    };

    public SampleXbarR() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        XbarR xbarr = new XbarR(axis, diameter);

        xbarr.UpperControlLimit.SetTitle("ucl = {0:0.0000}");

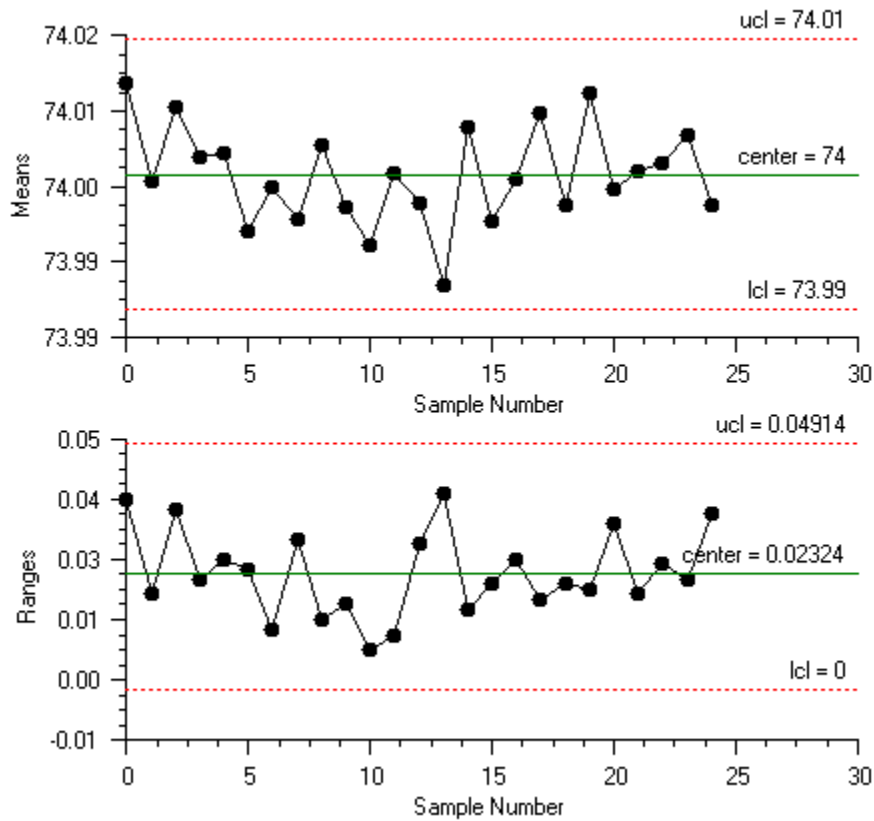
        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("Piston Ring Diameter");
        axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
        axis.AxisY.SetWindow(73.985, 74.015);
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleXbarR());
    }
}

```

XbarRCombo Example

This example combines the [XbarR](#) chart with the corresponding [RChart](#) into a single chart. This is done by adjusting the [Viewport](#) attribute values for the two subcharts (Montgomery 215).



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using Imsl.Chart2D.QC;  
  
public class SampleXbarRCombo : FrameChart {  
    static double[][] diameter = {  
        new double[] {74.03, 74.002, 74.019, 73.992, 74.008},  
        new double[] {73.995, 73.992, 74.001, 74.011, 74.004},  
        new double[] {73.988, 74.024, 74.021, 74.005, 74.002},  
        new double[] {74.002, 73.996, 73.993, 74.015, 74.009},  
        new double[] {73.992, 74.007, 74.015, 73.989, 74.014},  
        new double[] {74.009, 73.994, 73.997, 73.985, 73.993},  
        new double[] {73.995, 74.006, 73.994, 74, 74.005},  
        new double[] {73.985, 74.003, 73.993, 74.015, 73.988},  
        new double[] {74.008, 73.995, 74.009, 74.005, 74.004},  
    };  
}
```

```

        new double[] {73.998, 74, 73.99, 74.007, 73.995},
        new double[] {73.994, 73.998, 73.994, 73.995, 73.99},
        new double[] {74.004, 74, 74.007, 74, 73.996},
        new double[] {73.983, 74.002, 73.998, 73.997, 74.012},
        new double[] {74.006, 73.967, 73.994, 74, 73.984},
        new double[] {74.012, 74.014, 73.998, 73.999, 74.007},
        new double[] {74, 73.984, 74.005, 73.998, 73.996},
        new double[] {73.994, 74.012, 73.986, 74.005, 74.007},
        new double[] {74.006, 74.01, 74.018, 74.003, 74},
        new double[] {73.984, 74.002, 74.003, 74.005, 73.997},
        new double[] {74, 74.01, 74.013, 74.02, 74.003},
        new double[] {73.982, 74.001, 74.015, 74.005, 73.996},
        new double[] {74.004, 73.999, 73.99, 74.006, 74.009},
        new double[] {74.01, 73.989, 73.99, 74.009, 74.014},
        new double[] {74.015, 74.008, 73.993, 74, 74.01},
        new double[] {73.982, 73.984, 73.995, 74.017, 74.013}
    };

    public SampleXbarRCombo() {
        Chart chart = this.Chart;
        ShewhartControlChart[] charts =
            XbarR.CreateCharts(chart, diameter);
        AxisXY axis = (AxisXY)(charts[0].Axis);
        axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
        axis.AxisY.SetWindow(73.985, 74.015);
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleXbarRCombo());
    }
}

```

XmR

[XmR](#) is a moving range chart. It is used when only samples of size one are available. The moving range statistic is

$$MR_i = |x_i - x_{i-1}|$$

The control limits are computed using

$$UCL = \bar{x} + 3 \frac{\overline{MR}}{d_{2,2}}$$

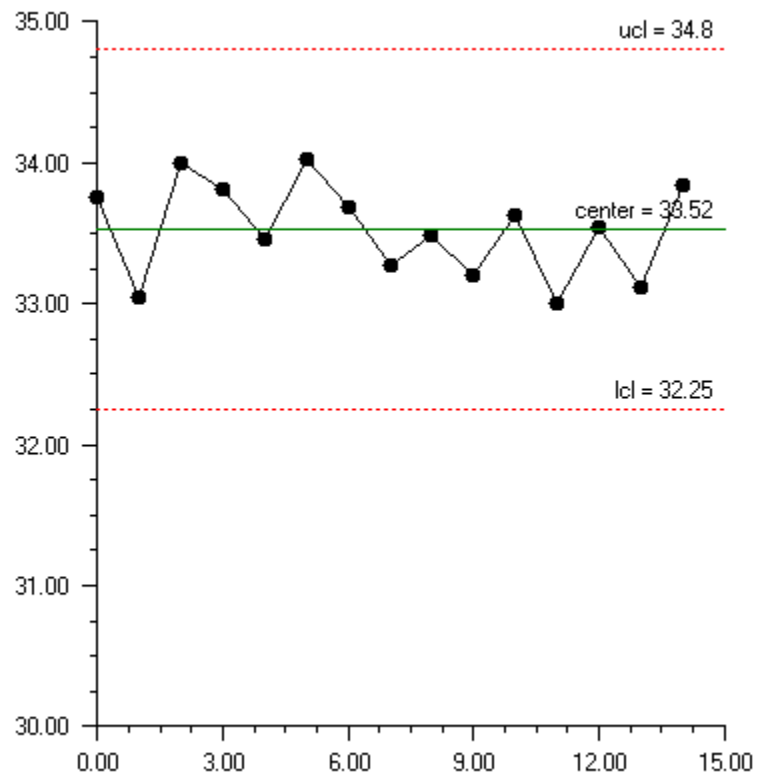
$$Centerline = \bar{x}$$

$$LCL = \bar{x} - 3 \frac{\overline{MR}}{d_{2,2}}$$

Where \bar{x} is the mean of the observations, \overline{MR} is the mean of the moving ranges and $d_{2,n}$ is the mean of the distribution of the ranges of n samples from the normal distribution with mean zero and standard deviation one.

XmR Example

The viscosity of aircraft primer paint was measured. Since the paint is produced in batches, only single samples are available (Montgomery 251).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleXmR : FrameChart {
    static double[] viscosity = {
```

```

        33.75, 33.05, 34.00, 33.81, 33.46, 34.02, 33.68,
        33.27, 33.49, 33.20, 33.62, 33.00, 33.54, 33.12, 33.84
    };

    public SampleXmR() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        XmR xmr = new XmR(axis, viscosity);
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleXmR());
    }
}

```

PChart

The [PChart](#) plots the proportion or fraction of defective products.

The production process is assumed to be stable and successive units are assumed independent. So each unit produced is a realization of a Bernoulli random variable with parameter p , the proportion defective.

The control limits are at

$$UCL = p + 3\sqrt{\frac{p(1-p)}{n}}$$

$$Centerline = p$$

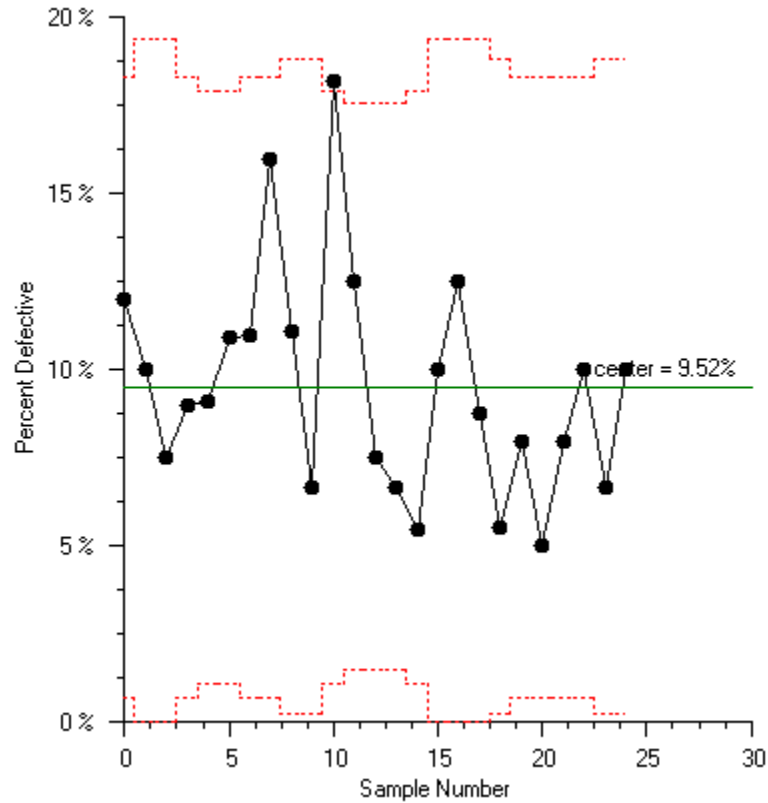
$$LCL = p - 3\sqrt{\frac{p(1-p)}{n}}$$

By default, p is the proportion of defects observed in the data. To use a known p , set the attribute [Center](#) to p .

PChart Example

Defects in the manufacturing of orange juice cans are measured. The number of defects in samples of 50 cans is counted (Montgomery 290).

The y-axis labels and the title on the control limits have been changed to use a percentage format.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SamplePChart : FrameChart {
    static int sampleSize = 50;
    static int[] numberDefects = {
        12, 15, 8, 10, 4, 7, 16, 9, 14, 10, 5, 6, 17, 12, 22, 8,
        10, 5, 13, 11, 20, 18, 24, 15, 9, 12, 7, 13, 9, 6
    };
};

public SamplePChart() {
    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);
    PChart pchart = new PChart(axis, sampleSize, numberDefects);

    pchart.LowerControlLimit.SetTitle("lcl = {0:0.00%}");
    pchart.CenterLine.SetTitle("center = {0:0.00%}");
    pchart.UpperControlLimit.SetTitle("ucl = {0:0.00%}");

    axis.AxisX.AxisTitle.SetTitle("Sample Number");
}
```

```

axis.AxisX.AxisLabel.TextFormat = "0";
axis.AxisY.AxisTitle.SetTitle("Percent Defective");
axis.AxisY.AxisLabel.TextFormat = "P0";
}

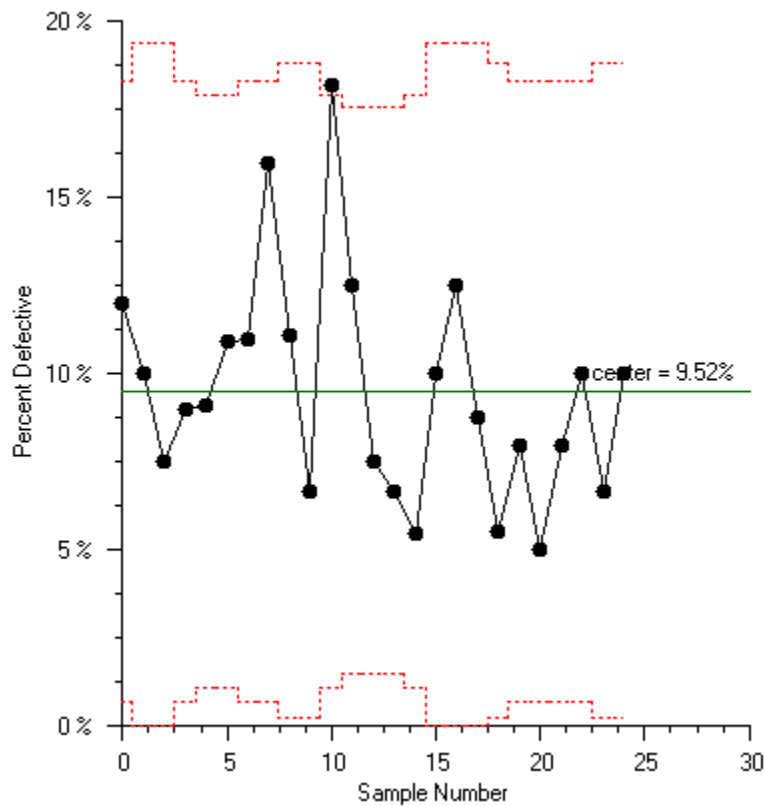
public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SamplePChart());
}
}

```

PChartUnequal Example

In this example a [PChart](#) is computed with unequal sample sizes. The upper and lower control limits are now stair-step lines (Montgomery 300).

The y-axis labels and the title on the center line have been changed to use a percentage format.



[\(Download Code\)](#)

```

using Imsl.Chart2D;
using Imsl.Chart2D.QC;

```

```

public class SamplePChartUnequal : FrameChart {
    static int[] sampleSize = {
        100, 80, 80, 100, 110, 110, 100, 100, 90, 90, 110, 120, 120,
        120, 110, 80, 80, 80, 90, 100, 100, 100, 100, 90, 90
    };
    static int[] numberDefects = {
        12, 8, 6, 9, 10, 12, 11, 16, 10, 6, 20, 15, 9, 8, 6, 8, 10,
        7, 5, 8, 5, 8, 10, 6, 9
    };

    public SamplePChartUnequal() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        PChart pchart = new PChart(axis, sampleSize, numberDefects);

        pchart.CenterLine.SetTitle("center = {0:0.00%}");

        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("Percent Defective");
        axis.AxisY.AxisLabel.TextFormat = "P0";
        axis.AxisY.SetWindow(0.0, 0.2);
        axis.AxisY.AutoscaleInput = 0;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(
            new SamplePChartUnequal());
    }
}

```

NpChart

[NpChart](#) is similar to [PChart](#), except that the number of defects per sample is plotted, not the sample rate. The position of the control limits are given by

$$UCL = np + 3\sqrt{np(1-p)}$$

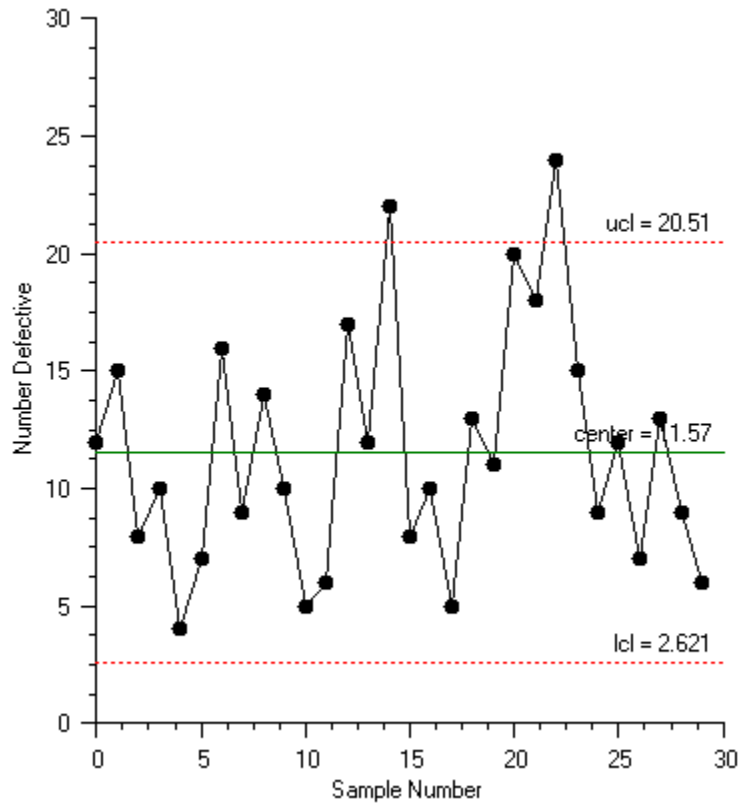
$$Centerline = np$$

$$LCL = np - 3\sqrt{np(1-p)}$$

where n is the number of items and p is the proportion of defective items.

NpChart Example

This example uses the orange juice can manufacturing data used earlier in the PChart example. In this example, the number of defects, rather than the defect rate is plotted.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleNpChart : FrameChart {
    static int sampleSize = 50;
    static int[] numberDefects = {
        12, 15, 8, 10, 4, 7, 16, 9, 14, 10, 5, 6, 17, 12, 22, 8,
        10, 5, 13, 11, 20, 18, 24, 15, 9, 12, 7, 13, 9, 6
    };
};

public SampleNpChart() {
    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);
    NpChart npchart = new NpChart(axis, sampleSize, numberDefects);

    axis.AxisX.AxisTitle.SetTitle("Sample Number");
    axis.AxisX.AxisLabel.TextFormat = "0";
}
```



```
        axis.AxisY.AxisTitle.SetTitle("Number Defective");
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleNpChart());
    }
}
```

CChart

[CChart](#) plots the number of defects or nonconformities.

$$UCL = c + k\sqrt{\bar{c}}$$

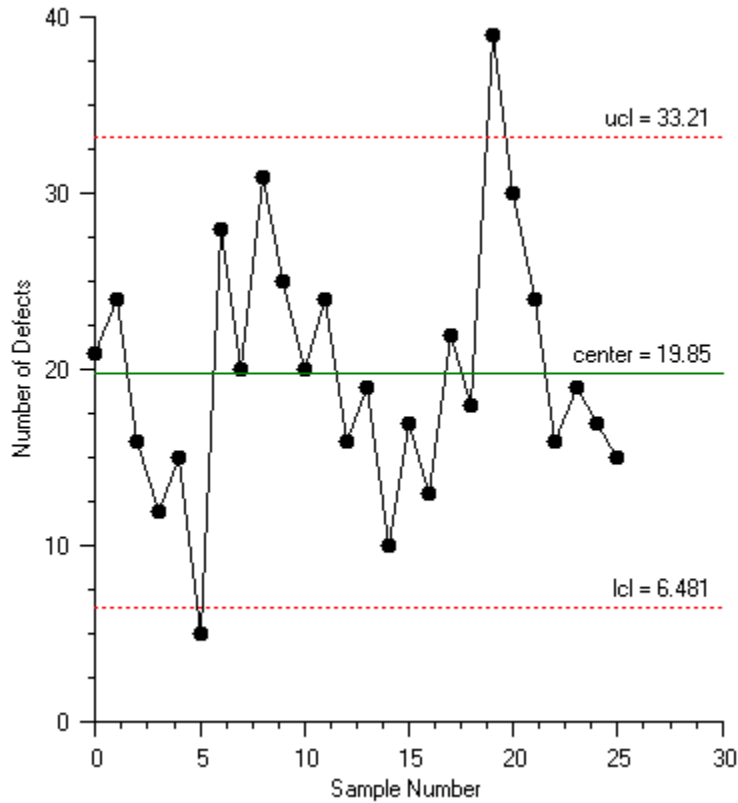
$$\text{Centerline} = c$$

$$LCL = c - k\sqrt{\bar{c}}$$

Where \bar{c} is the mean number of defects per sample and k is the value of the `ControlLimit` attribute for the line.

CChart Example

The number of defects in samples of 100 printed circuit boards was measured (Montgomery 321).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleCChart : FrameChart {
    static int[] numberDefects = {
        21, 24, 16, 12, 15, 5, 28, 20, 31, 25, 20, 24, 16,
        19, 10, 17, 13, 22, 18, 39, 30, 24, 16, 19, 17, 15
    };

    public SampleCChart() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        CChart cchart = new CChart(axis, numberDefects);

        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("Number of Defects");
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleCChart());
    }
}
```

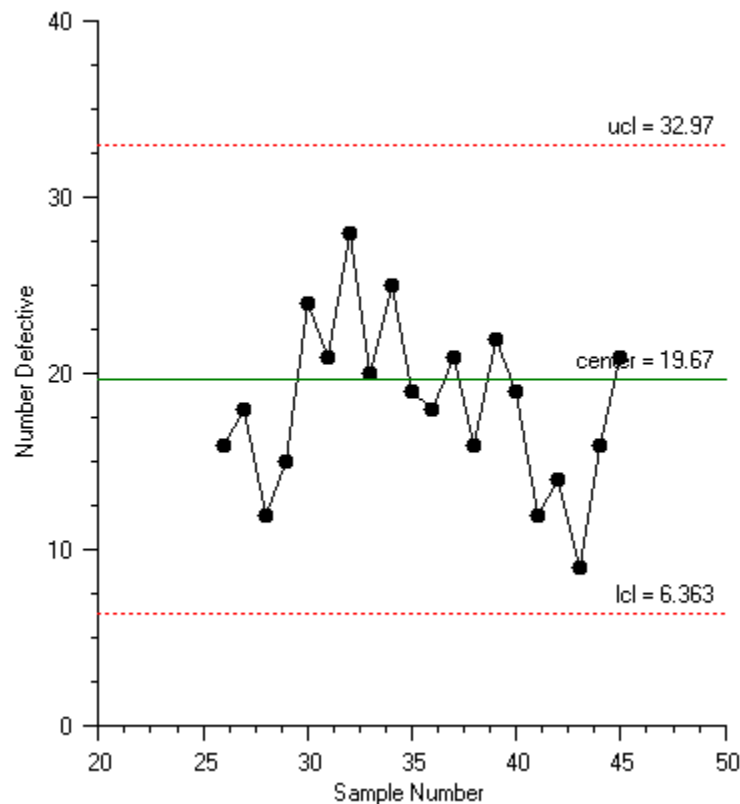
```
}  
}
```

CChartOmit Example

This is similar to the previous chart, but two points are omitted from the statistical computations.

To do this, first the censored chart is created with the bad points omitted. The positions of the control limits in this chart are saved. This censored chart is then removed from the chart.

The second step is to create a chart using later data points, but with the position of the control limit limits set to the values computed using the censored data.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using Imsl.Chart2D.QC;  
  
public class SampleCChartOmit : FrameChart {  
    static int[] numberDefects = {  
        21, 24, 16, 12, 15, 5, 28, 20, 31, 25, 20, 24, 16,  
        19, 10, 17, 13, 22, 18, 39, 30, 24, 16, 19, 17, 15  
    };  
};
```

```

static int[] censoredNumberDefects = {
    21, 24, 16, 12, 15, /*5,*/ 28, 20, 31, 25, 20, 24, 16,
    19, 10, 17, 13, 22, 18, /*39,*/ 30, 24, 16, 19, 17, 15
};

static int[] furtherNumberDefects = {
    16, 18, 12, 15, 24, 21, 28, 20, 25,
    19, 18, 21, 16, 22, 19, 12, 14, 9, 16, 21
};

public SampleCChartOmit() {
    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);

    CChart censoredCChart = new CChart(axis,
        censoredNumberDefects);
    double lcl = censoredCChart.LowerControlLimit.GetValue()[0];
    double center = censoredCChart.Center;
    double ucl = censoredCChart.UpperControlLimit.GetValue()[0];
    censoredCChart.Remove();

    double[] x = new double[furtherNumberDefects.Length];
    for (int i = 0; i < x.Length; i++) {
        x[i] = numberDefects.Length + i;
    }
    CChart fullCChart = new CChart(axis, furtherNumberDefects);
    fullCChart.ControlData.SetX(x);
    fullCChart.LowerControlLimit.SetValue(lcl);
    fullCChart.CenterLine.SetValue(center);
    fullCChart.UpperControlLimit.SetValue(ucl);

    axis.AxisX.AxisTitle.SetTitle("Sample Number");
    axis.AxisX.AxisLabel.TextFormat = "0";
    axis.AxisY.AxisTitle.SetTitle("Number Defective");
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleCChartOmit());
}
}

```

UChart

[UChart](#) is a chart for monitoring the defect rate when defects are rare.

$$UCL = \bar{u} + 3\sqrt{\frac{\bar{u}}{n}}$$

$$Centerline = \bar{u}$$

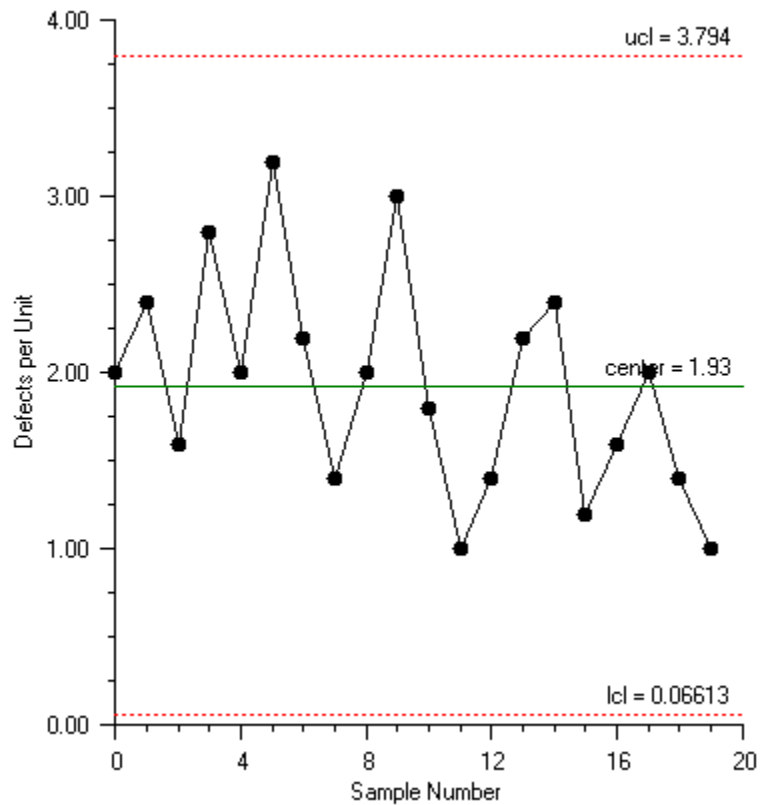
$$LCL = \bar{u} - 3\sqrt{\frac{\bar{u}}{n}}$$

Where \bar{u} is the observed average number of defects per unit and n is the number of inspection units.

UChart Example

Samples Sizes are Equal

The number of defects in the manufacturing of computers was measured. There were 20 samples, each containing 5 computers. The center line is at 1.93, the average number of defects per computer (Montgomery 318).



[\(Download Code\)](#)

```

using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleUChart : FrameChart {
    static int sampleSize = 5;
    static int[] numberDefects = {
        10, 12, 8, 14, 10, 16, 11, 7, 10, 15, 9, 5,
        7, 11, 12, 6, 8, 10, 7, 5
    };

    public SampleUChart() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        UChart uchart = new UChart(axis, sampleSize, numberDefects);

        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("Defects per Unit");
    }

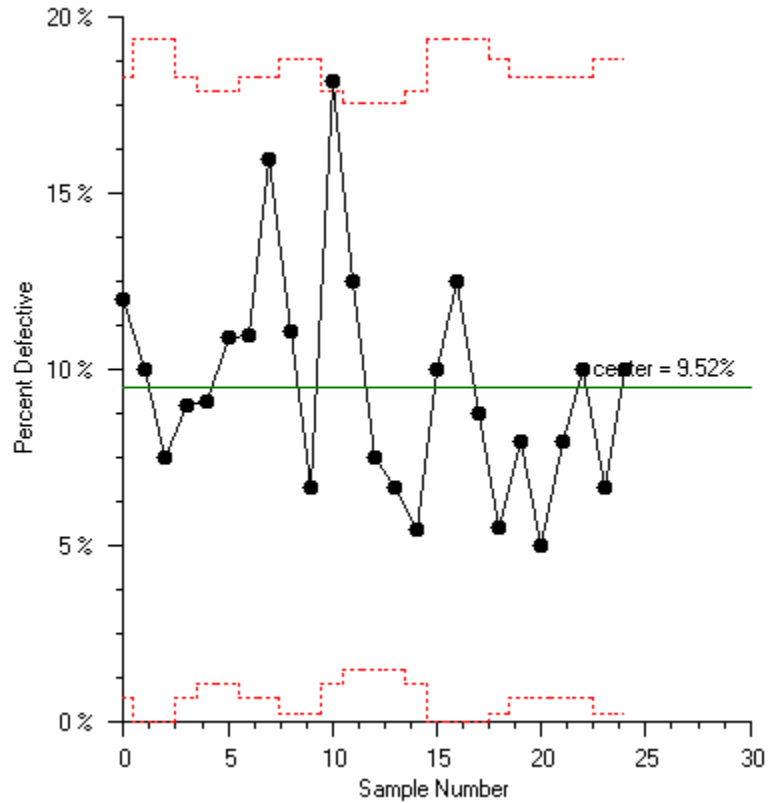
    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleUChart());
    }
}

```

UChartUnequal Example

Unequal Sample Sizes

Defects in dying rolls of cloth were measured. The number of defects per 50 square meters was counted. Since the sizes of the rolls differed, the number of inspection units per roll varied. The center line is at 1.423, the average number of defects per 50 square meters (Montgomery, 321).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleUChartUnequal : FrameChart {
    static double[] inspectionUnitsPerRoll = {
        10, 8, 13, 10, 9.5, 10, 12, 10.5, 12, 12.5
    };
    static int[] numberDefects = {
        14, 12, 20, 11, 7, 10, 21, 16, 19, 23
    };

    public SampleUChartUnequal() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        Uchart uchart = new Uchart(axis, inspectionUnitsPerRoll,
numberDefects);

        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("Defects per Unit");
    }
}
```

```

    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleUChartUnequal());
    }
}

```

EWMA

[EWMA](#) is the exponentially weighted moving average control chart. It is very effective in detecting small process shifts, but is slower than Shewhart charts at detecting large process shifts.

The exponentially weighted moving average is defined to be

$$z_i = \lambda x_i + (1 - \lambda) z_{i-1}$$

where $0 < \lambda \leq 1$ is a constant and the starting value is μ_0 , the expected mean.

The control limits in EWMA are defined by the equations:

$$UCL = \mu_0 + 3\sigma \sqrt{\frac{\lambda}{2-\lambda}} [1 - (1-\lambda)^{2i}]$$

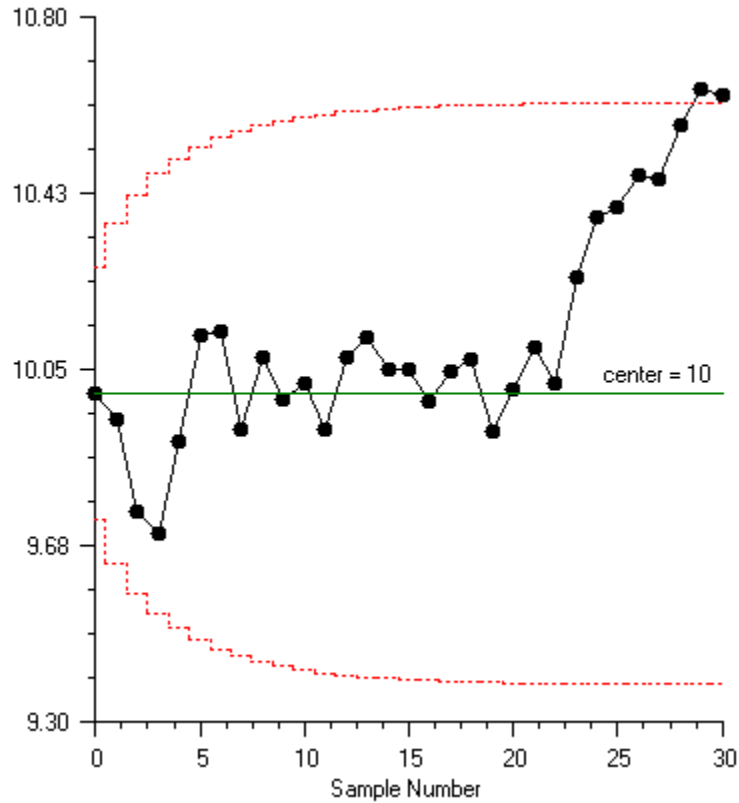
$$Centerline = \mu_0$$

$$LCL = \mu_0 - 3\sigma \sqrt{\frac{\lambda}{2-\lambda}} [1 - (1-\lambda)^{2i}]$$

Where μ_0 is the historical mean, σ is the historical standard deviation, and i is the sample number. Because of the presence of i the control limits are stair-steps, not constants.

EWMA Example

The expected mean is 10., the expected standard deviation is 1.0 and λ is 0.10. Also, the control limit values are 2.7, not the default value of 3 (Montgomery 428).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleEWMA : FrameChart {
    static double[] data = {
        9.45, 7.99, 9.29, 11.66, 12.16, 10.18, 8.04, 11.46,
        9.20, 10.34, 9.03, 11.47, 10.51, 9.40, 10.08, 9.37,
        10.62, 10.31, 8.52, 10.84, 10.90, 9.33, 12.29, 11.50,
        10.60, 11.08, 10.38, 11.62, 11.31, 10.52
    };
};

public SampleEWMA() {
    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);
    double lambda = 0.10;
    double mean = 10.0;
    double stdev = 1.0;
    EWMA ewma = new EWMA(axis, data, lambda, mean, stdev);
    ewma.LowerControlLimit.ControlLimitValue = -2.7;
    ewma.UpperControlLimit.ControlLimitValue = 2.7;
}
```

```

axis.AxisX.AxisTitle.SetTitle("Sample Number");
axis.AxisX.AxisLabel.TextFormat = "0";
axis.AxisY.SetWindow(9.3, 10.8);
axis.AxisY.AutoscaleInput = 0;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleEWMA());
}
}

```

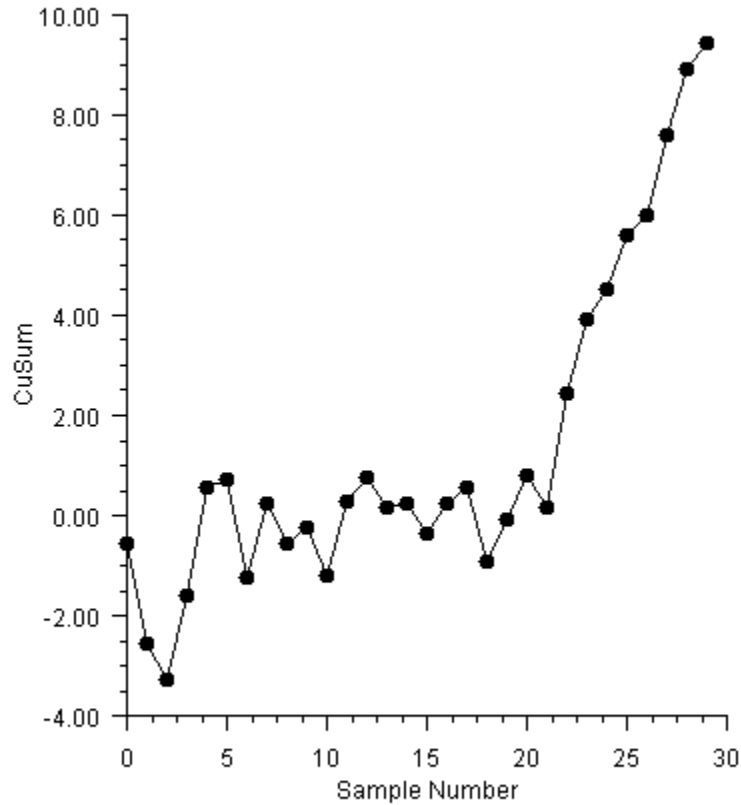
CuSum

[CuSum](#) is the cumulative sum control chart. It plots the cumulative sum of the deviations of the expected value. If μ_0 is the expected mean for a process and \bar{x}_i are the sample means then the cumulative sum is

$$C_i = C_{i-1} + (\bar{x}_i - \mu_0)$$

CuSum Example

The data used is the same as for the [EWMA](#) example.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleCuSum : FrameChart {
    static double[] data = {
        9.45, 7.99, 9.29, 11.66, 12.16, 10.18, 8.04, 11.46, 9.20, 10.34,
        9.03,
        11.47, 10.51, 9.40, 10.08, 9.37, 10.62, 10.31, 8.52, 10.84, 10.90,
        9.33, 12.29, 11.50, 10.60, 11.08, 10.38, 11.62, 11.31, 10.52
    };
};

public SampleCuSum() {
    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);
    CuSum cusum = new CuSum(axis, data);
    cusum.ExpectedMean = 10.0;
}
```

```

        axis.AxisX.AxisTitle.SetTitle("Sample Number");
        axis.AxisX.AxisLabel.TextFormat = "0";
        axis.AxisY.AxisTitle.SetTitle("CuSum");
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleCuSum());
    }
}

```

CuSumStatus

[CuSumStatus](#) is a tabular or status [CuSum](#) chart. The tabular CuSum statistics are

$$C_i^+ = \max\left(0, x_i - (\mu_0 + K) + C_{i-1}^+\right)$$

$$C_i^- = \max\left(0, (\mu_0 + K) - x_i + C_{i-1}^-\right)$$

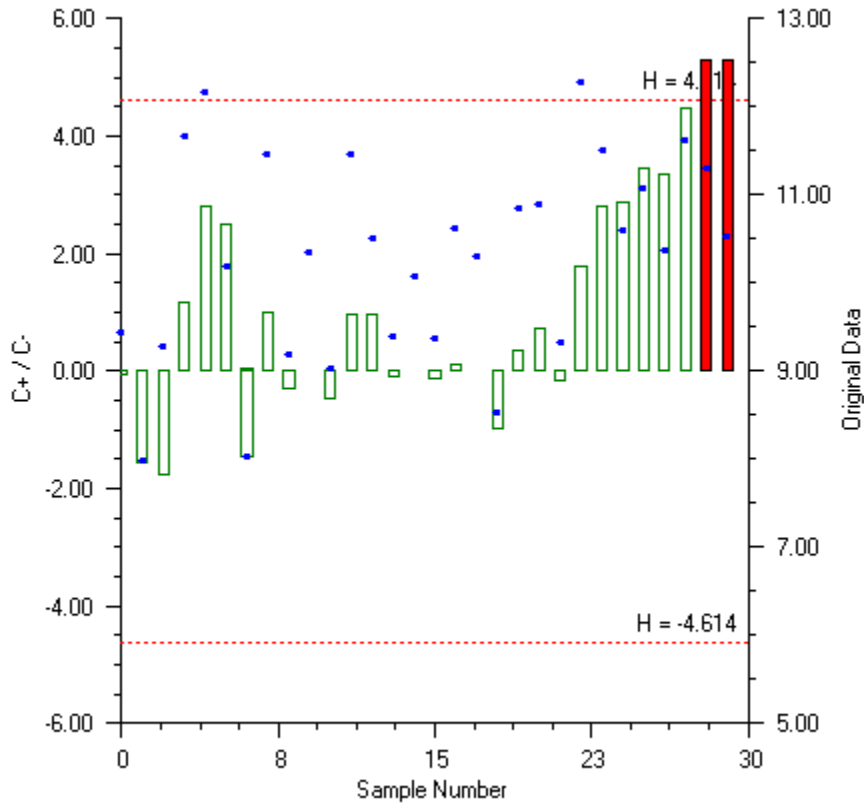
By default, both statistics have initial value zero. The parameter K is the slack value (or allowance or reference value) and μ_0 is the expected mean.

The [CuSumStatus](#) chart contains two bar charts: a bar chart of C_i^+ above the x -axis and a bar chart of C_i^- below the x -axis. There are also control limits at plus and minus H . The value of H can be set either as an absolute value or as a relative value h . They are related by $H = h\sigma$, where σ is the standard deviation. By default, bars which are out-of-control are filled red while in-control bars are green. The data is also plotted on the chart.

The [CuSumStatus](#) has a `Print` method to print the C_i^+ and C_i^- values as well as N_i^+ and N_i^- , where N_i^+ is the number of consecutive periods since C_i^+ rose above zero.

CuSumStatus Example

This example uses the same data as used for the [CuSum](#) and [EWMA](#) examples. In this example $H = 4\sigma$.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;
using System.Drawing;

public class SampleCuSumStatus : FrameChart {
    static double[] data = {
        9.45, 7.99, 9.29, 11.66, 12.16, 10.18, 8.04, 11.46,
        9.20, 10.34, 9.03, 11.47, 10.51, 9.40, 10.08, 9.37,
        10.62, 10.31, 8.52, 10.84, 10.90, 9.33, 12.29, 11.50,
        10.60, 11.08, 10.38, 11.62, 11.31, 10.52
    };
};

public SampleCuSumStatus() {
    double expectedMean = 10;
    double slackValue = 0.5;

    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);
    CuSumStatus cusumStatus =
```

```

        new CuSumStatus(axis, data, expectedMean, slackValue);
cusumStatus.RelativeH = 4;
cusumStatus.Print();

axis.AxisX.AxisTitle.SetTitle("Sample Number");
axis.AxisX.AxisLabel.TextFormat = "0";
axis.AxisY.AxisTitle.SetTitle("C+ / C-");

axis.AxisX.SetWindow(0, 30);
axis.AxisX.AutoscaleInput = 0;

cusumStatus.AddDataMarkers();
cusumStatus.DataMarkers.MarkerSize = 0.5;
cusumStatus.DataMarkers.MarkerColor = Color.Blue;
cusumStatus.DataMarkersAxis.AxisY.AxisTitle.SetTitle(
    "Original Data");

cusumStatus.BarPlus.GetBarSet(0,0).FillType =
    Data.FILL_TYPE_NONE;
cusumStatus.BarMinus.GetBarSet(0,0).FillType =
    Data.FILL_TYPE_NONE;
cusumStatus.BarPlus.GetBarSet(0,0).FillOutlineColor =
    Color.Green;
cusumStatus.BarMinus.GetBarSet(0,0).FillOutlineColor =
    Color.Green;
    }

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleCuSumStatus());
}
}

```

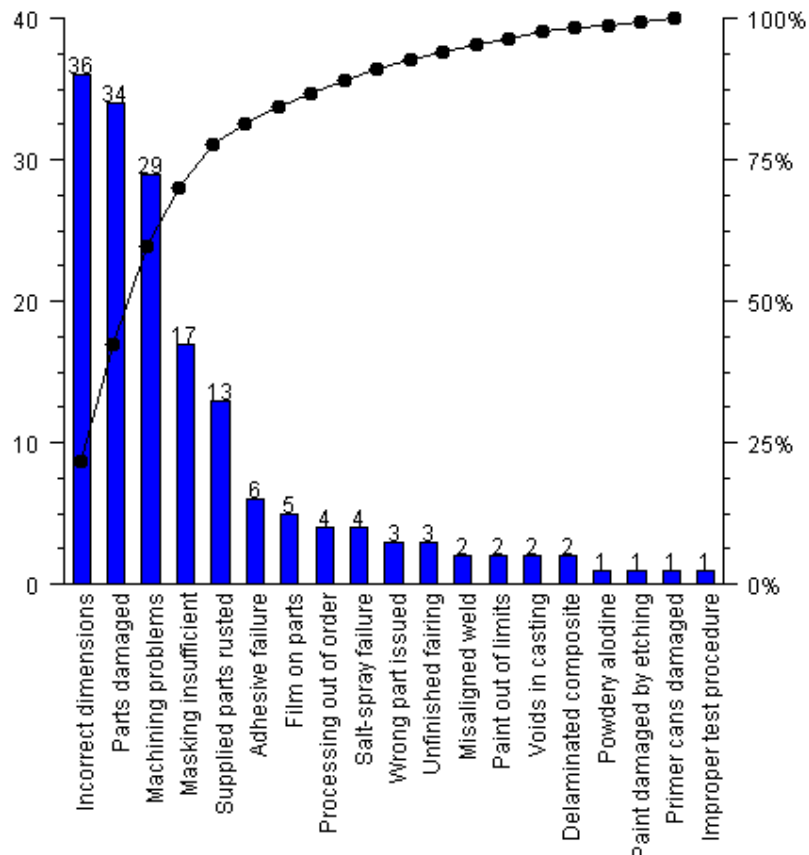
Pareto Chart

A [ParetoChart](#) is a frequency distribution of attribute data. The bars are ordered by the number of defects, with the attribute category having the largest number of defects appearing first.

There is an option to add a cumulative percentage line to the chart. This is the percent of defects accounted for by the current item and all items to its left. If the cumulative percentage line is added, a second axis is created on the right representing the cumulative percentage from 0% to 100%. The units of the original axis, which always appear on the left, represent the number of defects, 36.

ParetoChart Example

The number of defects attributable to 1 of 19 of a variety of causes was collected (Montgomery 179). In this example, the “Incorrect dimensions” defect category has the largest number of defects, 36.



[\(Download Code\)](#)

```

using Imsl.Chart2D;
using Imsl.Chart2D.QC;

public class SampleParetoChart : FrameChart {
    static string[] labels = {
        "Parts damaged",
        "Machining problems",
        "Supplied parts rusted",
        "Masking insufficient",
        "Misaligned weld",
        "Processing out of order",
        "Wrong part issued",
        "Unfinished fairing",
        "Adhesive failure",
        "Powdery alodine",
        "Paint out of limits",
        "Paint damaged by etching",
        "Film on parts",
    };
}

```

```

        "Primer cans damaged",
        "Voids in casting",
        "Delaminated composite",
        "Incorrect dimensions",
        "Improper test procedure",
        "Salt-spray failure"
    };

    static int[] numberDefects = {
        34, 29, 13, 17, 2, 4, 3, 3, 6,
        1, 2, 1, 5, 1, 2, 2, 36, 1, 4
    };

    public SampleParetoChart() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        ParetoChart pareto = new ParetoChart(axis, labels, numberDefects);

        Data cumulativeLine = pareto.AddCumulativeLine();
        cumulativeLine.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;

        pareto.LabelType = ParetoChart.LABEL_TYPE_Y;
        pareto.TextFormat = "0";
        pareto.FillColor = System.Drawing.Color.Blue;
        axis.AxisX.AxisLabel.TextAngle = 90;

        double[] vp = axis.GetViewport();
        vp[0] = 0.1;
        vp[3] = 0.7;
        axis.SetViewport(vp);
        cumulativeLine.Axis.SetViewport(vp);
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleParetoChart());
    }
}

```

Cumulative Probability

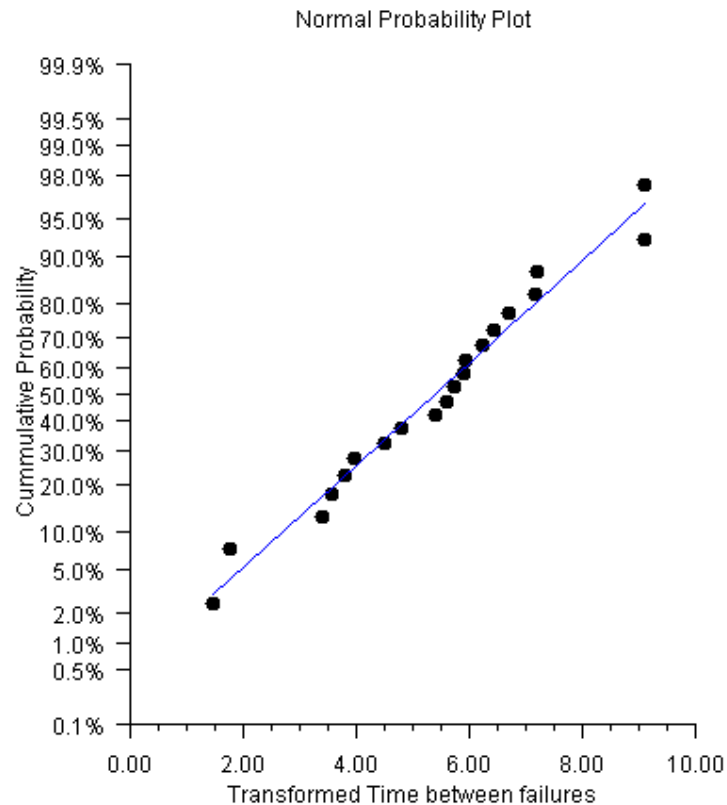
If the defect rate is very small there will be long runs when the number of defects is zero. In this situation the [CChart](#) and [UChart](#) are ineffective. An alternative to defect counts is to measure the time between defects.

If the distribution of defect occurrences is Poisson, then the distribution of times between defects is exponential. Unfortunately the exponential distribution is highly skewed. Nelson suggested transforming to Weibull random variables using the transformation $x = y^{1/3.6}$.

CumulativeProbability Example

The number of hours between failures is measured. A normal probability plot is constructed from the transformed data. A linear regression to the transformed data is also computed. To fit a

regression with the normal probability axis, the regression variable needs to be transformed using the inverse normal cumulative distribution function (Montgomery, Example 6-21, 327).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Chart2D.QC;
using Imsl.Stat;

public class SampleCumulativeProbability : FrameChart {
    static double[] timeBetweenFailures = {
        286, 948, 536, 124, 816, 729, 4, 143, 431, 8, 2837,
        596, 81, 227, 603, 492, 1199, 1214, 2831, 96
    };

    static double[] ticks = {
        0.001, 0.005, 0.01, 0.02, 0.05, 0.10, 0.20, 0.30,
        0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 0.98,
        0.99, 0.995, 0.999
    };
};
```

```

public SampleCumulativeProbability() {
    Chart chart = this.Chart;
    AxisXY axis = new AxisXY(chart);
    double a = ticks[0];
    double b = ticks[ticks.Length-1];
    chart.ChartTitle.SetTitle("Normal Probability Plot");
    axis.AxisX.AxisTitle.SetTitle(
        "Transformed Time between failures");
    axis.AxisY.AxisTitle.SetTitle("Cumulative Probability");
    axis.AxisY.Transform = Axis.TRANSFORM_CUSTOM;
    Transform transform = new NormalTransform();
    axis.AxisY.CustomTransform = transform;
    axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
    axis.AxisY.SetWindow(a, b);
    axis.AxisY.TextFormat = "P1";
    axis.AxisY.SetTicks(ticks);
    axis.AxisY.MinorTick.IsVisible = false;

    int n = timeBetweenFailures.Length;
    double[] x = new double[n];
    double[] y = new double[n];
    for (int i = 0; i < x.Length; i++) {
        x[i] = System.Math.Pow(timeBetweenFailures[i], 1.0/3.6);
    }
    Sort.Ascending(x);
    for (int i = 0; i < x.Length; i++) {
        y[i] = (double)(i+0.5) / (double)n;
    }
    Data data = new Data(axis, x, y);
    data.DataType = Data.DATA_TYPE_MARKER;
    data.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;

    // Compute an plot a regression line
    LinearRegression lr = new LinearRegression(1, true);
    for (int i = 0; i < n; i++) {
        lr.Update(new double[]{x[i]}, InvCdf.Normal(y[i]));
    }
    double[] coef = lr.GetCoefficients();
    double[] lry = new double[x.Length];
    for (int i = 0; i < x.Length; i++) {
        lry[i] = Cdf.Normal(coef[0]+coef[1]*x[i]);
    }
    Data lrData = new Data(axis, x, lry);
    lrData.DataType = Data.DATA_TYPE_LINE;
    lrData.LineColor = System.Drawing.Color.Blue;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(
        new SampleCumulativeProbability());
}
}

class NormalTransform : Transform {

```

```

private double scaleA, scaleB;

// Initializes the mappings between user and coordinate space.
public void SetupMapping(Axis1D axis1d) {
    double[] w = axis1d.GetWindow();
    double t = InvCdf.Normal(w[0]);
    scaleB = 1.0 / (InvCdf.Normal(w[1]) - t);
    scaleA = -scaleB * t;
}

// Maps a point in [0,1] to a probability.
public double MapUnitToUser(double unit) {
    return Cdf.Normal((unit - scaleA) / scaleB);
}

// Maps a probability to the interval [0,1].
public double MapUserToUnit(double p) {
    return scaleA + scaleB * InvCdf.Normal(p);
}
}

```

Chapter 4: Drawing Elements

Chart 2D Drawing Elements

This chapter discusses these IMSL C# Numerical Library drawing elements:

This chapter discusses these IMSL C# Numerical Library Chart 2D drawing elements: IMSL C# Numerical Library

- [“Line Attributes”](#) on page 108
- [“Marker Attributes”](#) on page 109
- [“Fill Area Attributes”](#) on page 111
- [“Text Attributes”](#) on page 114
- [“Labels”](#) on page 117
- [“AxisXY”](#) on page 121
- [“Background”](#) on page 142
- [“Legend”](#) on page 146
- [“Colormaps”](#) on page 150
- [“Tool Tips”](#) on page 151

Line Attributes

All lines, except for those used to draw markers or outline filled regions, are affected by the attributes described in this section. These include axis lines and lines drawn when a [Data](#) node is rendered with its `DataType` attribute having its [DATA_TYPE_LINE](#) bit set.

Attribute LineColor

`LineColor` is a [Color](#)-valued attribute that determines the color of the line. Its default value is [Color.Black](#). IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.LineColor](#) should be used to set the line color.

Attribute LineWidth

`LineWidth` is a double-valued attribute that determines the thickness of the lines. Its default value is 1.0. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore







[AbstractChartNode.LineWidth](#) should be used to set the line width and [ChartNode.SetLineDashPattern](#) should be used to set the line dash pattern.

Attribute LineDashPattern

`LineDashPattern` is a double-array-valued attribute that determines the line pattern used to draw the line. It defaults to a solid line. Alternate entries in the array represent the lengths of the opaque and transparent segments of the dashes. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.SetLineDashPattern](#) should be used to set the line dash pattern.

Some dash patterns are defined. They are [DASH_PATTERN_DOT](#), [DASH_PATTERN_DASH](#) and [DASH_PATTERN_DASH_DOT](#).

Samples

	Normal
	LineWidth = 2
	LineWidth = 4
	LineDashPattern = DASH_PATTERN_DOT
	LineDashPattern = DASH_PATTERN_DASH
	LineDashPattern = DASH_PATTERN_DASH_DOT

Marker Attributes

Markers are drawn when a [Data](#) node is rendered with its `DataType` attribute having its [DATA_TYPE_MARKER](#) bit set. Drawing of markers is affected by the attributes described in this section. Note that even though some markers are drawn using lines, the line attributes do not apply to markers.

An alternative to markers are images, which can be used to draw arbitrary symbols instead of markers.

Attribute MarkerType

`MarkerType` is an integer-valued attribute that determines which marker will be drawn. There are constants defined in [ChartNode](#) for the marker types. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.MarkerType](#) should be used to set the line dash pattern. The default value is [MARKER_TYPE_PLUS](#). The following are all of the defined marker types. For clarity, these are drawn larger than normal.

- + MARKER_TYPE_PLUS
- * MARKER_TYPE_ASTERISK
- × MARKER_TYPE_X
- MARKER_TYPE_HOLLOW_SQUARE
- MARKER_TYPE_FILLED_SQUARE
- △ MARKER_TYPE_HOLLOW_TRIANGLE
- ▲ MARKER_TYPE_FILLED_TRIANGLE
- ◇ MARKER_TYPE_HOLLOW_DIAMOND
- ◆ MARKER_TYPE_FILLED_DIAMOND
- ⊕ MARKER_TYPE_DIAMOND_PLUS
- ⊠ MARKER_TYPE_SQUARE_X
- ⊞ MARKER_TYPE_SQUARE_PLUS
- ⊗ MARKER_TYPE_OCTAGON_X
- ⊕ MARKER_TYPE_OCTAGON_PLUS
- MARKER_TYPE_HOLLOW_CIRCLE
- MARKER_TYPE_FILLED_CIRCLE
- ⊗ MARKER_TYPE_CIRCLE_X
- ⊕ MARKER_TYPE_CIRCLE_PLUS
- ⊙ MARKER_TYPE_CIRCLE_CIRCLE

Attribute MarkerColor

`MarkerColor` is a [Color](#)-valued attribute that determines the color of the marker. Its default value is [Color.Black](#). IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.MarkerColor](#) should be used to set the marker color.

Attribute MarkerSize

`MarkerSize` is a double-valued attribute that determines the size of the marker. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.MarkerSize](#) should be used to set the marker size. Its default value is 1.0. The actual size of the drawn marker, in pixels, is $0.007 * \text{MarkerSize} * \text{width}$, where *width* is the width of the [Control](#) containing the chart.

Attribute MarkerThickness

`MarkerThickness` is a double-valued attribute that determines the thickness of the lines used to draw the marker. Its default value is 1.0. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.MarkerThickness](#) should be used to set the marker thickness.

Attribute MarkerDashPattern

`MarkerDashPattern` is a double-array-valued attribute that determines the line pattern used to draw the marker. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.SetMarkerDashPattern](#) should be used to set the marker dash pattern. It defaults to a solid line. Alternate entries in the array represent the lengths of the opaque and transparent segments of the dashes.

Some dash patterns are defined. They are [DASH_PATTERN_DOT](#), [DASH_PATTERN_DASH](#) and [DASH_PATTERN_DASH_DOT](#).

NOTE: `MarkerDashPattern` is a double-array-valued attribute that determines the line pattern used to draw the marker. It defaults to a solid line. Alternate entries in the array represent the lengths of the opaque and transparent segments of the dashes. These patterns will be more recognizable with larger marker sizes.

Samples

- Normal
- `MarkerThickness = 2`
- `MarkerThickness = 4`
- `MarkerDashPattern = DASH_PATTERN_DOT`
- `MarkerDashPattern = DASH_PATTERN_DASH`
- `MarkerDashPattern = DASH_PATTERN_DASH_DOT`

Fill Area Attributes

FillOutlineType

`FillOutlineType` is an integer-value attribute that turns on or off the drawing of an outline around filled areas. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.FillOutlineType](#) should be used to set the fill outline type. Its value

should be [FILL_TYPE_NONE](#) (for outline off) or [FILL_TYPE_SOLID](#) (for outline on). The default is to draw solid lines.

FillOutlineColor

`FillOutlineColor` is a [Color](#)-valued attribute that determines the color used to outline the filled regions. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.FillOutlineColor](#) should be used to set the fill outline color. The outline is drawn only if the attribute `FillOutlineType` has the value [FILL_TYPE_SOLID](#). Its default value is [Color.Black](#).

FillType

`FillType` is an integer-value attribute that turns on or off the drawing of the interior of filled areas. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.FillType](#) should be used to set the fill outline color. Its value should be

- [FILL_TYPE_NONE](#) for fill off.
- [FILL_TYPE_SOLID](#) for fill by a single, solid color. This is the default.
- [FILL_TYPE_GRADIENT](#) for fill by a color gradient.
- [FILL_TYPE_PAINT](#) for fill by a [Brush](#) object. This is usually a [TextureBrush](#).

FillColor

`FillColor` is a [Color](#)-valued attribute that determines the color used to fill a region with a solid color. Its default value is [Color.Black](#). IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.FillColor](#) should be used to set the fill color.

Gradient





`Gradient` is a [Color](#) array-valued attribute that fills a region with a gradient color. It does not have a default value. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.SetGradient](#) should be used to set the gradient.

The value of `Gradient` should be an array of four colors. These are the colors at the four corners of a square. In order they are: lower-left, lower-right, upper-right and upper-left.

- If the lower-side colors are equal (`color[0]` equals `color[1]`) and the upper-side colors are equal (`color[2]` equals `color[3]`), then a vertical gradient is drawn.
- If the left-side colors are equal (`color[0]` equals `color[3]`) and the right-side colors are equal (`color[1]` equals `color[2]`), then a horizontal gradient is drawn.

- If the lower-right and upper-left colors (`color[1]` and `color[3]`) are null, then a diagonal gradient is drawn using the lower-left (`color[0]`) and upper-right (`color[2]`) colors.
- If the lower-left and upper-right colors (`color[0]` and `color[2]`) are null, then a diagonal gradient is drawn using the lower-right (`color[1]`) and upper-left (`color[3]`) colors.

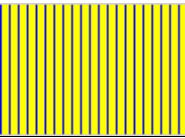
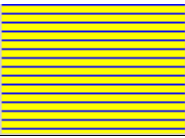
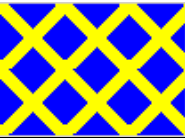

If none of the above patterns exist, then no gradient is drawn.

Vertical		<code>SetGradient(Color.Yellow, Color.Yellow, Color.Red, Color.Red)</code>
Horizontal		<code>SetGradient(Color.Yellow, Color.Red, Color.Red, Color.Yellow)</code>
Diagonal		<code>SetGradient(Color.Yellow, null, Color.Red, null)</code>
Diagonal		<code>SetGradient(null, Color.Yellow, null, Color.Red)</code>

FillPaint

`FillPaint` is a [Brush](#)-valued attribute that fills a region with a tiled pattern. It does not have a default value. The method [ChartNode.SetFillPaint](#) is used to specify the `FillPaint` object. The class [FillPaint](#) contains utilities to define some useful paint patterns.

Some Examples of FillPaint

	<code>FillPaint.VerticalStripe(10, 5, Color.Yellow,Color.Blue)</code>
	<code>FillPaint.HorizontalStripe(10, 5, Color.Yellow,Color.Blue)</code>
	<code>FillPaint.Diamond(36, 5, Color.Blue,Color.Yellow)</code>
	<code>FillPaint.Checkerboard(24, Color.Red,Color.Yellow)</code>

The `FillPaint` attribute can also be set using an [Image](#), which is used to tile filled regions.

Text Attributes

Attribute Font

`Text` is drawn using `Font` objects constructed using the `FontName`, `FontSize` and `FontStyle` attributes. The `ChartNode.Font` property does not save the `Font` object, but sets these three attributes.

This arrangement allows one to specify font size and style at lower nodes and change the font face at the root node.

Multiline text strings are allowed. They are created by newline characters in the string that creates the text item.

Attribute FontName

`FontName` is a string-valued attribute that specifies the logical font name or a font face name. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore `AbstractChartNode.FontName` should be used to set the font name.

Attribute `FontSize`

`FontSize` is an integer-valued attribute that specifies the point size of the font. Its default value is 12. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.FontSize](#) should be used to set the font size.

Attribute `FontStyle`

`FontStyle` is a `System.Drawing.FontStyle`-valued attribute that specifies the font style. This can be a bitwise combination of any of the standard types in the [FontStyle enumeration](#). Its default value is `FontStyle.Regular`. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.FontStyle](#) should be used to set the font style.

Attribute `TextAngle`

`TextAngle` is an integer-valued attribute that specifies the angle, in degrees, at which text is drawn. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [ChartNode.TextAngle](#) should be used to set the text angle. The angle is measured counterclockwise. Its default value is 0.

Attribute `TextColor`

`TextColor` is a [Color](#)-valued attribute that specifies the color in which the text is drawn. Its default value is [Color.Black](#). IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.TextColor](#) should be used to set the text color.

Attribute `TextFormat`

`TextFormat` is a `Format`-valued or a `String`-valued attribute that specifies how to format string objects. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.TextFormat](#) should be used to set the text format. The .NET Framework provides a wide variety of [formatting options](#) and convenient standard [format specifiers](#).

For numeric values, specifiers like “C” for Currency, “E” for scientific exponential, and “P” for Percentage are available. `DateTime` objects can use “d” for a Short date pattern or “D” for a Long date pattern and many others. Custom Numeric Format Strings can be created using “0” for a zero placeholder, “#” for a digit placeholder and others. The default value is “0.00”

Attribute `TextFormatProvider`

`TextFormatProvider` is an [IFormatProvider](#)-valued attribute that supplies culture-specific formatting information. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.TextFormatProvider](#) should be used to set the text format provider. The default value is null so the default `Culture-Info`, [DateTimeFormatInfo](#) and [NumberFormatInfo](#) are utilized.

Attribute `Title`

`Title` is a [Text](#)-valued that contains the title for a node. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore, most chart classes will set a title using method

[ChartNode.SetTitle](#). The chart title is unique in that the [ChartNode.ChartTitle](#) property should be used. The class `Text` holds a string and its alignment and offset information.

The alignment of a `Text` object is the bitwise combination of one of

- [TEXT_X_LEFT](#), [TEXT_X_CENTER](#), [TEXT_X_RIGHT](#), and one of
- [TEXT_Y_BOTTOM](#), [TEXT_Y_CENTER](#), [TEXT_Y_TOP](#).

The offset moves the start of the text away from the reference point in the direction of the alignment. So if the alignment bit `TEXT_X_LEFT` is set and the offset is greater than zero then the text starts a distance further to the left than if the offset were zero. The distance moved is the value of offset times the default marker size. The offset is usually zero, but the [Data](#) node sets it to 2.0 for labeling data points.

A `Text` object is drawn relative to a reference point. The alignment specifies the position of the reference point on the box that contains the text. There are nine such possible positions. In the following samples, the reference point is marked with a square.

If the text is drawn at an angle, then the alignment is relative to the horizontally/vertically aligned bounding box of the text.

Samples

Following are sample fonts in styles plain, italic and bold. These may look different on different platforms.

■ Default
■
■ TEXT_X_LEFT | TEXT_Y_TOP
■
■ TEXT_X_CENTER | TEXT_Y_TOP
■
■ TEXT_X_RIGHT | TEXT_Y_TOP
■ TEXT_X_LEFT | TEXT_Y_CENTER
■
■ TEXT_X_CENTER | TEXT_Y_CENTER
■
■ TEXT_X_RIGHT | TEXT_Y_CENTER
■ TEXT_X_LEFT | TEXT_Y_BOTTOM
■
■ TEXT_X_CENTER | TEXT_Y_BOTTOM
■
■ TEXT_X_RIGHT | TEXT_Y_BOTTOM
■

If the text is drawn at an angle, then the alignment is relative to the horizontally/ vertically aligned bounding box of the text.

Labels

Labels annotate data points or pie slices. As a degenerate case they can be used to place text on a chart without drawing a point. Labels are controlled by the value of the attribute `LabelType` in a [Data](#) node.

Multiline labels are allowed. They are created by newline characters in the string that creates the label.

Attribute `LabelType`

The attribute `LabelType` takes on one of the values listed below. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.LabelType](#) should be used to set the label type.

- [LABEL_TYPE_NONE](#) for no label. This is the default.
- [LABEL_TYPE_X](#) label with the value of the x -coordinate.
- [LABEL_TYPE_Y](#) label with the value of the y -coordinate.
- [LABEL_TYPE_TITLE](#) label with the value of the Title attribute.
- [LABEL_TYPE_PERCENT](#) label with the percentage value. This applies only to [PieSlice](#) objects.

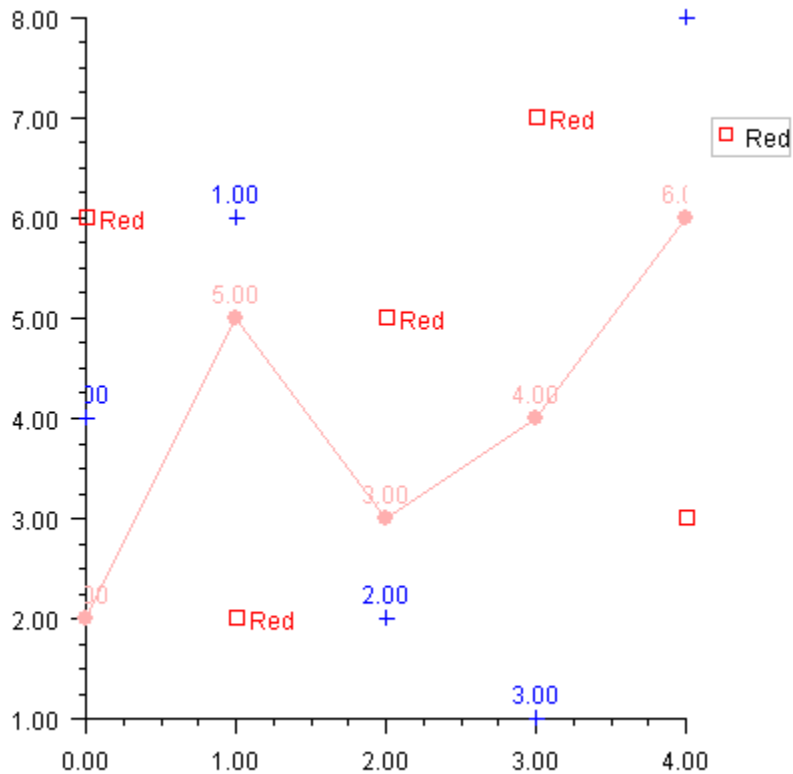
Data Point Labeling Example

This example shows three data sets, each labeled in a different fashion.

The first data set is blue and the points are labeled by the value of their x -coordinates.

The second data set is pink and the points are labeled by the value of their y -coordinates. The data set is drawn with both markers and lines.

The third data set is red and the points are labeled with the [Data](#) node's `Title` attribute.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleLabels : FrameChart {

    public SampleLabels() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        chart.Legend.IsVisible = true;

        // Data set 1 - labeled with X
        double[] y1 = {4, 6, 2, 1, 8};
        Data data1 = new Data(axis, y1);
        data1.DataType = Data.DATA_TYPE_MARKER;
        data1.MarkerColor = Color.Blue;
        data1.TextColor = Color.Blue;
        data1.LabelType = Data.LABEL_TYPE_X;

        // Data set 2 - labeled with Y
        double[] y2 = {2, 5, 3, 4, 6};
```

```

Data data2 = new Data(axis, y2);
data2.DataType = Data.DATA_TYPE_MARKER | Data.DATA_TYPE_LINE;
data2.MarkerColor = Color.Pink;
data2.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
data2.LineColor = Color.Pink;
data2.TextColor = Color.Pink;
data2.LabelType = Data.LABEL_TYPE_Y;

// Data set 3 - labeled with Title
double[] y3 = {6, 2, 5, 7, 3};
Data data3 = new Data(axis, y3);
data3.DataType = Data.DATA_TYPE_MARKER;
data3.MarkerColor = Color.Red;
data3.MarkerType = Data.MARKER_TYPE_HOLLOW_SQUARE;
data3.LineColor = Color.Red;
data3.TextColor = Color.Red;
data3.LabelType = Data.LABEL_TYPE_TITLE;
data3.SetTitle("Red");
data3.GetTitle().Alignment = Data.TEXT_X_LEFT | Data.TEXT_Y_CENTER;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleLabels());
}
}

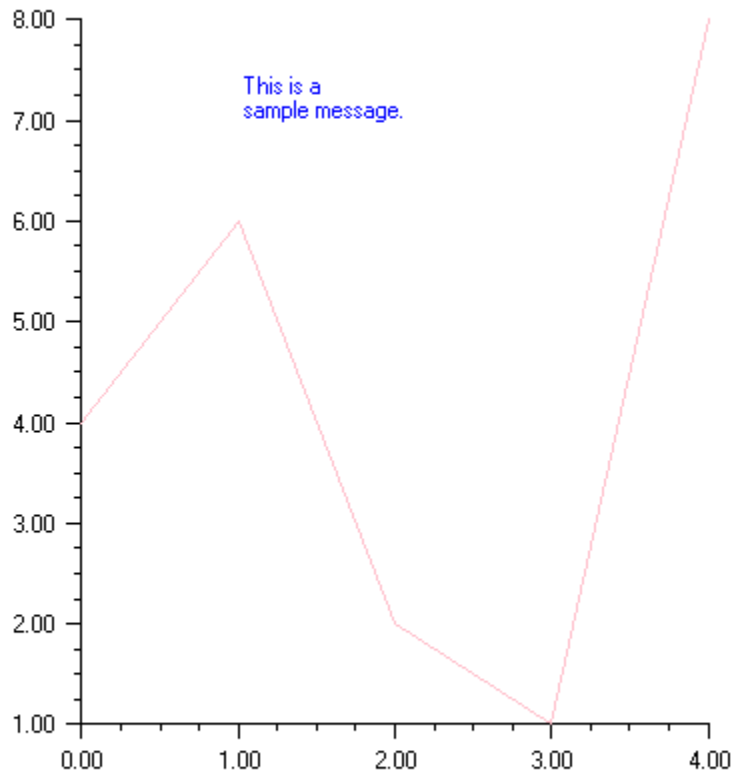
```

Annotation

The [Annotation](#) class can be used to place text on a chart. In this example a text message is drawn at (1,7) as its bottom left corner.

Note that it is a two line message. Newlines in the string are reflected in the chart.

The text alignment is set to [TEXT_X_LEFT](#) | [TEXT_Y_BOTTOM](#), so (1,7) is the lower left corner of the text's bounding box (see "[Attribute Title](#)" on page 115).



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using System.Drawing;  
  
public class SampleLabelMessage : FrameChart {  
  
    public SampleLabelMessage() {  
        Chart chart = this.Chart;  
        AxisXY axis = new AxisXY(chart);  
  
        double[] y = {4, 6, 2, 1, 8};  
        Data data = new Data(axis, y);  
        data.DataType = Data.DATA_TYPE_LINE;  
        data.LineColor = Color.Pink;  
  
        Text message = new Text("This is a\nsample message.");  
        message.Alignment = Data.TEXT_X_LEFT | Data.TEXT_Y_BOTTOM;  
    }  
}
```



```
        Annotation messageAnnotation =
            new Annotation(axis, message, 1.0, 7.0);
        messageAnnotation.TextColor = Color.Blue;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleLabelMessage());
    }
}
```

AxisXY

The [AxisXY](#) node is the basis of many chart types, including scatter, line, area and error bar. Its parent node must be the root [Chart](#) node.

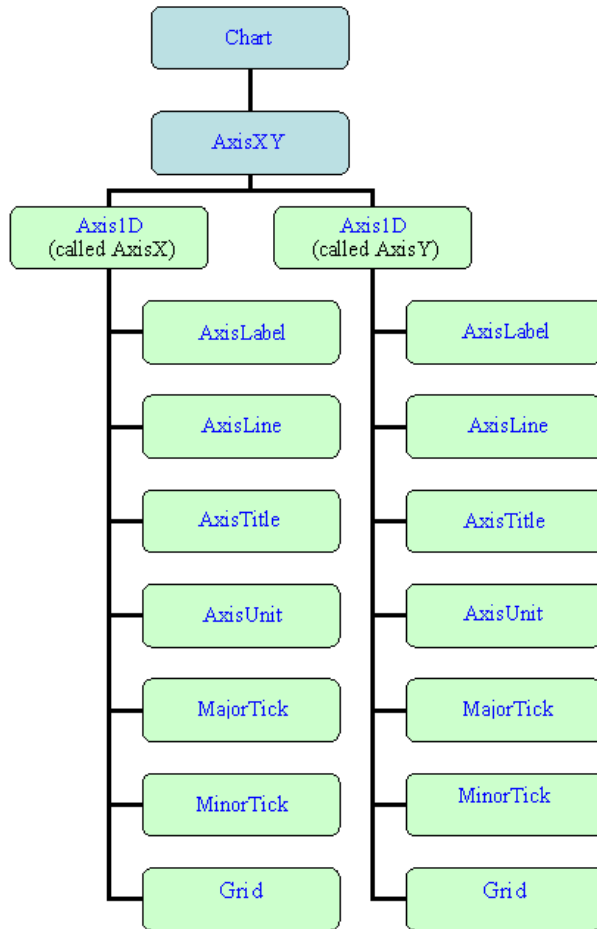
When an [AxisXY](#) node is created, it creates two [Axis1D](#) nodes. They can be obtained by using the methods [AxisXY.AxisX](#) and [AxisXY.AxisY](#). Each of the [Axis1D](#) nodes in turn creates additional child nodes, as seen in the diagram below.

Properties can be chained together, so the *x*-axis line can be retrieved using

```
axis.AxisX.AxisLine
```

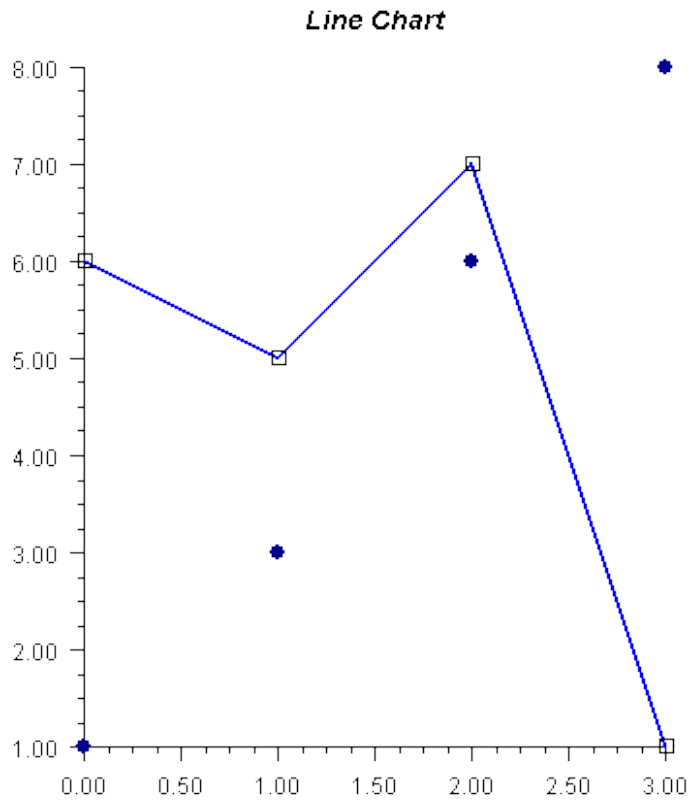
The code to set the *x*-axis line to blue is

```
axis.AxisX. AxisLine.LineColor = Color.Blue;
```



Axis Layout

The layout of an `AxisXY` chart, such as the one below, is controlled by the attributes `window`, `Density`, and `Number`.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class Line : FrameChart
{
    public Line()
    {
        Chart chart = Chart;
        AxisXY axis = new AxisXY(chart);
        chart.ChartTitle.FontSize = 14;
        chart.ChartTitle.FontStyle = System.Drawing.FontStyle.Italic;
        chart.ChartTitle.SetTitle("Line Chart");

        double[] y1 = {6, 5, 7, 1};
        Data data1 = new Data(axis, y1);
        data1.DataType = Data.DATA_TYPE_LINE|Data.DATA_TYPE_MARKER;
        data1.LineColor = System.Drawing.Color.Blue;
        data1.LineWidth = 2.0;
        data1.MarkerType = Data.MARKER_TYPE_HOLLOW_SQUARE;
    }
}
```

```

        data1.SetTitle("Blue Line");

        double[] y2 = {1, 3, 6, 8};
        Data data2 = new Data(axis, y2);
        data2.DataType = Data.DATA_TYPE_MARKER;
        data2.MarkerColor = System.Drawing.Color.DarkBlue;
        data2.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
        data2.SetTitle("Markers");
    }

    public static void Main(string[] argv)
    {
        System.Windows.Forms.Application.Run(new Line());
    }
}

```

Window

`Window` is a double-array-valued attribute that contains the axis limits. Its value is $\{min, max\}$. The [AxisXY.SetWindow](#) should be used to set the window. For the above chart, the value of the `Window` attribute for the x -axis is $[0, 3]$ and for the y -axis is $[1, 8]$.

Number

`Number` is an integer-valued attribute that contains the number of major tick marks along an axis. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.Number](#) should be used to set the number of ticks. In an `Axis1D` node its default value is 5, which is also the value in the above example.

Density

`Density` is the number of minor tick marks per major tick mark. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.Density](#) should be used to set the `Density`. Its default value is 4, which is also the value in the example.

Transform

The x - and y -axes may be linear, logarithmic, or customized, as specified by the `Transform` attribute. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.Transform](#) should be used to set the transform. This attribute can have the values:

- [TRANSFORM_LINEAR](#) indicating a linear axis. This is the default.
- [TRANSFORM_LOG](#) indicating a logarithmic axis.
- [TRANSFORM_CUSTOM](#) indicating a custom transformation. The transformation specified by the `CustomTransform` attribute is used.

CustomTransform

A customized transformation is used when the `Transform` attribute has the value [TRANSFORM_CUSTOM](#). IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.CustomTransform](#) should be used to set the `CustomTransform`. A custom transform is an object implementing the [Transform](#) interface. It defines a mapping from the interval specified by the `Window` attribute to and from the interval $[0, 1]$. See “[Custom Transform](#)” on page 135 for more information.

The class [TransformDate](#) implements the `Transform` interface. It maps from a regular calendar to one without weekends, which is useful for charting stock prices that are defined only on weekdays.

Autoscale

Autoscaling is used to automatically determine the attribute `Window` (the range of numbers along an axis) and the attribute `Number` (the number of major tick marks). The goal is to adjust the attributes so that the data fits on the axes and the axes have “nice” numbers as labels.

Autoscaling is done in two phases. In the first (“input”) phase the actual range is determined. In the second (“output”) phase chart attributes are updated.

Attribute AutoscaleInput

The action of the input phase is controlled by the value of attribute `AUTOSCALE_INPUT` in the axis node. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.AutoscaleInput](#) should be used to indicate how auto scaling is to be done. It can have one of three values.

- [AUTOSCALE_OFF](#) turns off autoscaling.
- [AUTOSCALE_DATA](#) scans the values in the [Data](#) nodes that are attached to the axis to determine the data range. This is the default value.
- [AUTOSCALE_WINDOW](#) uses the value of the `Window` attribute to determine the data range.

Attribute AutoscaleOutput

The value of the `AUTOSCALE_OUTPUT` attribute can be the bitwise combination of the following values.

- [AUTOSCALE_OFF](#) no attributes updated.
- [AUTOSCALE_NUMBER](#) updates the value of the `Number` attribute. This is the number of major tick marks along the axis.
- [AUTOSCALE_WINDOW](#) updates the value of the `Window` attribute. This is the range of numbers displayed along the axis.

IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.AutoscaleOutput](#) should be used to indicate how auto scaling is to be done. The default is `AUTOSCALE_NUMBER | AUTOSCALE_WINDOW`; both the attributes `Number` and `Window` are adjusted.

Axis Label

The [AxisLabel](#) node controls the labeling of an axis. [Axis1D.AxisLabel](#) should be used to set the `AxisLabel` attributes. The drawing of this node is controlled by the “[Text Attributes](#)” on page 114.

Scientific Notation

If the values along an axis are large, scientific notation is more readable than a decimal format with many zeros. In this example the y-axis is labeled with scientific notation where each number has exactly two fractional digits displayed. Use `axis.AxisY.AxisLabel.TextFormat` and format pattern, "0.00E0". See [Formatting Types](#) in the .Net Framework Developer's Guide for details on number formatting pattern.

Date Labels

If the [TextFormat](#) attribute for an axis is set to a date format, then the axis is scaled and labeled as a date/time axis instead of as a real axis.

Date information passed to the [Data](#) constructor must be a `double` or `long`, usually obtained from the [Ticks](#) property of a [DateTime](#) instance.

Skipping Weekends

An additional feature of `Date` axes is the ability to skip weekends. This feature is often needed for charting stock price data.

To skip weekends it is necessary to adjust the autoscaling for weekdays-only. This is done by setting the attribute [SkipWeekends](#) to `true`. It is also necessary to set a custom transformation, [TransformDate](#), on the axis. This is shown in the following example, which is a modification of the example in the previous section.

Skipping weekends is intended only for data sets where no weekend data exists. It will not give the expected results if the data set contains weekend data.

String Labels

Any array of strings can be used to label the tick marks using the [SetLabels\(String\[\]\)](#) method. The `SetLabels(String[])` method sets the `Number` attribute to the number of strings.

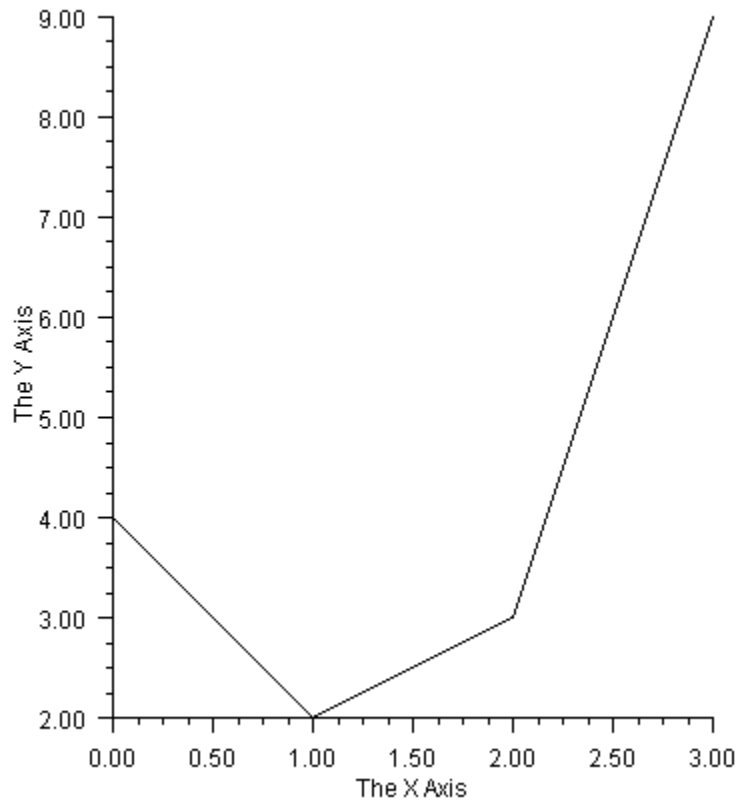
Axis Title

The [AxisTitle](#) node controls the titling of an axis. The drawing of this node is controlled by the “[Text Attributes](#)” on page 114.

Axes are titled with the value of the `Title` attribute in the `AxisTitle` node. By default, the title is empty.

Setting the Title

To set an axis title, set the `Title` attribute in the `AxisTitle` node. In this example both the *x*-axis and *y*-axis titles are set.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
  
public class SampleAxisTitle : FrameChart {  
  
    public SampleAxisTitle() {  
        Chart chart = this.Chart;  
        AxisXY axis = new AxisXY(chart);  
        double[] y = {4, 2, 3, 9};  
        Data data = new Data(axis, y);  
  
        axis.AxisX.AxisTitle.SetTitle("The X Axis");  
        axis.AxisY.AxisTitle.SetTitle("The Y Axis");  
    }  
}
```

```
public static void Main(string[] argv) {  
    System.Windows.Forms.Application.Run(new SampleAxisTitle());  
}  
}
```

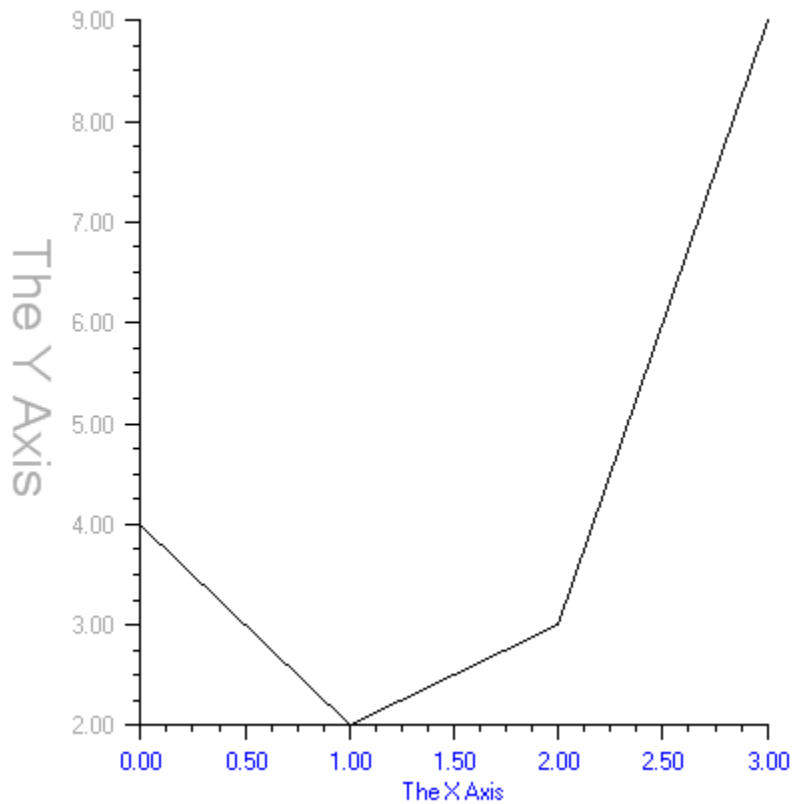
More Formatting

An axis title, like any other text string, can have further formatting applied.

The [FontName](#) attribute is set to “Serif” in the axis node. This value is then inherited by all of its ancestor nodes.

The [TextColor](#) attribute is set differently in the *x*-axis and *y*-axis nodes. Note that this setting is inherited by both the `AxisTitle` and nodes within the same axis.

The *y*-axis title node has its [FontSize](#) attribute set to 20, so it is larger. Also, its [TextAngle](#) attribute is set to -90. By default, the *y*-axis title is drawn at a 90 degree angle, so the -90 degree setting flips the title from its usual position.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
```



```

using System.Drawing;

public class SampleAxisTitleFormatted : FrameChart {

    public SampleAxisTitleFormatted() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        double[] y = {4, 2, 3, 9};
        Data data = new Data(axis, y);

        axis.FontName = "Serif";

        axis.AxisX.TextColor = Color.Blue;
        axis.AxisX.AxisTitle.SetTitle("The X Axis");

        axis.AxisY.TextColor = Color.DarkGray;
        axis.AxisY.AxisTitle.SetTitle("The Y Axis");
        axis.AxisY.AxisTitle.TextAngle = -90;
        axis.AxisY.AxisTitle.FontSize = 20;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(
            new SampleAxisTitleFormatted());
    }
}

```

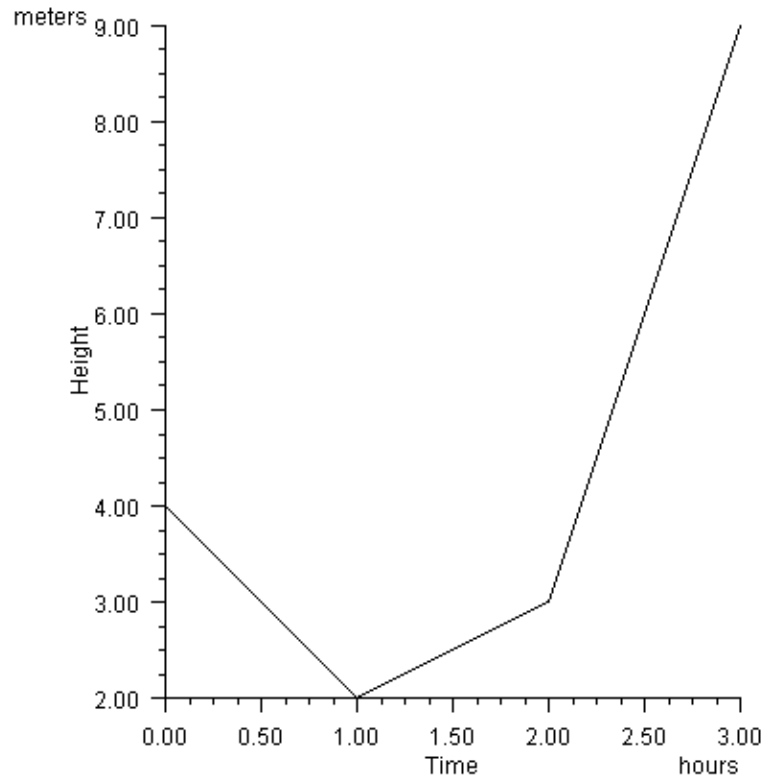
Axis Unit

The [AxisUnit](#) node controls the placing of a unit tag on an axis. The tag is the value of the `title` attribute in the node. By default, it is empty.

The axis unit is used for labeling only; it has no other effect on the chart.

Setting the Axis Unit

In this example, the axis unit for the *x*-axis is set to “hours” and the axis unit for the *y*-axis is set to “meters”. While not required, the axis titles are also set.



[\(Download Code\)](#)

```
using Imsl.Chart2D;

public class SampleAxisUnit : FrameChart {

    public SampleAxisUnit() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        double[] y = {4, 2, 3, 9};
        Data data = new Data(axis, y);

        axis.AxisX.AxisTitle.SetTitle("Time");
        axis.AxisY.AxisTitle.SetTitle("Height");

        axis.AxisX.AxisUnit.SetTitle("hours");
        axis.AxisY.AxisUnit.SetTitle("meters");
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleAxisUnit());
    }
}
```

}

Major and Minor Tick Marks

The nodes [MajorTick](#) and [MinorTick](#) control the drawing of tick marks on an [AxisXY](#).

The location of the major tick marks can be set explicitly, using the [Axis1D.SetTicks](#) method. However, it is usually easier to allow autoscaling to automatically set the tick locations (see “[Autoscale](#)” on page 125).

Attribute TickLength

The length of the tick marks is proportional to the screen size. They can be made relatively longer or shorter by setting the attribute `TickLength`. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.TickLength](#) should be used to set the tick length. Its default value is 1.0. If its value is negative, the tick marks are drawn in the opposite direction: i.e., into the center of the plot region rather than away from it.

Attribute Number

`Number` is the number of major tick marks along an axis. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.Number](#) should be used to set the number of ticks.

Attribute Density

`Density` is the number of minor tick marks in each interval between major tick marks. The minor ticks are equally spaced in user coordinates. If the `Transform` attribute is not [TRANSFORM_LINEAR](#), then they will not be equally spaced on the screen. IMSL charting is largely made up of classes that inherit from `ChartNode`. Therefore [AbstractChartNode.Density](#) should be used to set the `Density`.

Attribute FirstTick

The `FirstTick` attribute, in an [Axis1D](#) node, is the position of the first major tick mark. [Axis1D.FirstTick](#) should be used to set the location of the first tick mark. The default value is the 0-th element of the `Windows` attribute.

Attribute TickInterval

The `TickInterval` attribute, in an [Axis1D](#) node, is the interval between tick marks in the user coordinates. “[Axis1D.TickInterval](#)” should be used to set the tick interval. If this attribute is not explicitly set, its value is computed from the attributes [Number](#), [Window](#) and [Transform](#).

Attribute Ticks

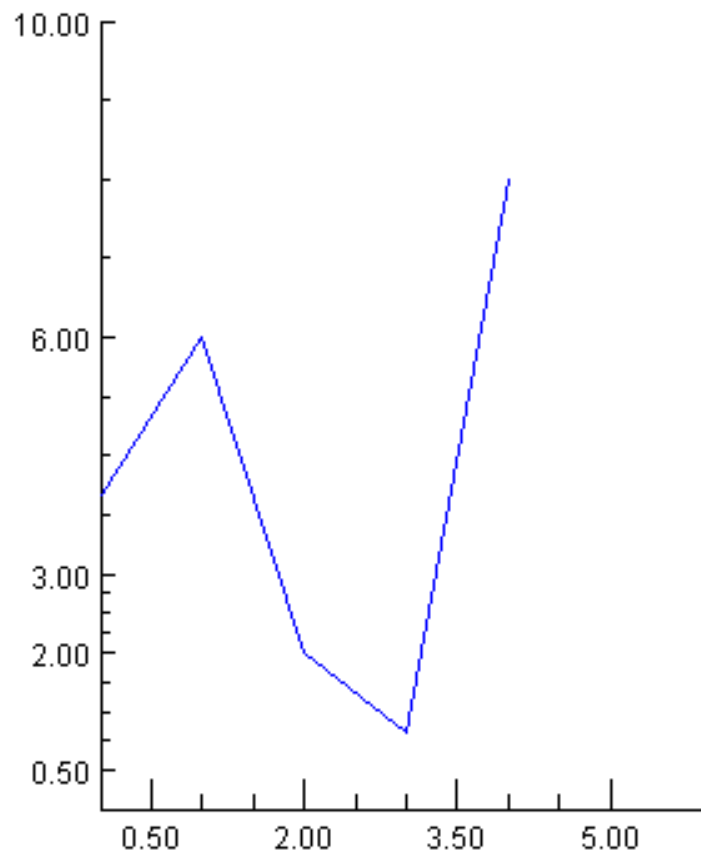
The `Ticks` attribute, in an `Axis1D` node, contains the position of the major tick marks. [Axis1D.SetTicks](#) should be used to set the ticks. If this attribute is not explicitly set, its value is computed from the attributes [FirstTick](#), [TickInterval](#), [Number](#), [Window](#) and [Transform](#).

Example

This example shows the effects of the tick mark attributes. Note that autoscaling is turned off so that the attribute values are not overridden (see “[Autoscale](#)” on page 125).

On the x -axis, there are four major tick marks (`Number`), starting with 0.5 (`FirstTick`) at an interval of 1.5 (`TickInterval`). There are three minor tick intervals (`Density`) between each major tick mark. The tick marks are twice as long and are drawn in the opposite direction as normal (`TickLength`).

On the y -axis, the tick mark locations are set explicitly by the attribute `Ticks`. This automatically sets the attribute `Number`. The `TickLength` is set to -1, so the tick marks are drawn inward (to the right) instead of outward (to the left).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleTicks : FrameChart {

    public SampleTicks() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        axis.AutoscaleOutput = Axis.AUTOSCALE_OFF;

        axis.AxisX.SetWindow(0.0, 6.0);
        axis.AxisX.Density = 3;
        axis.AxisX.Number = 4;
        axis.AxisX.FirstTick = 0.5;
        axis.AxisX.TickInterval = 1.5;
        axis.AxisX.TickLength = -2;

        axis.AxisY.SetWindow(0.0, 10.0);
        double[] ticksY = {0.5, 2.0, 3.0, 6.0, 10.0};
        axis.AxisY.SetTicks(ticksY);
        axis.AxisY.TickLength = -1;

        double[] y = {4, 6, 2, 1, 8};
        Data data = new Data(axis, y);
        data.DataType = Data.DATA_TYPE_LINE;
        data.LineColor = Color.Blue;
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleTicks());
    }
}
```

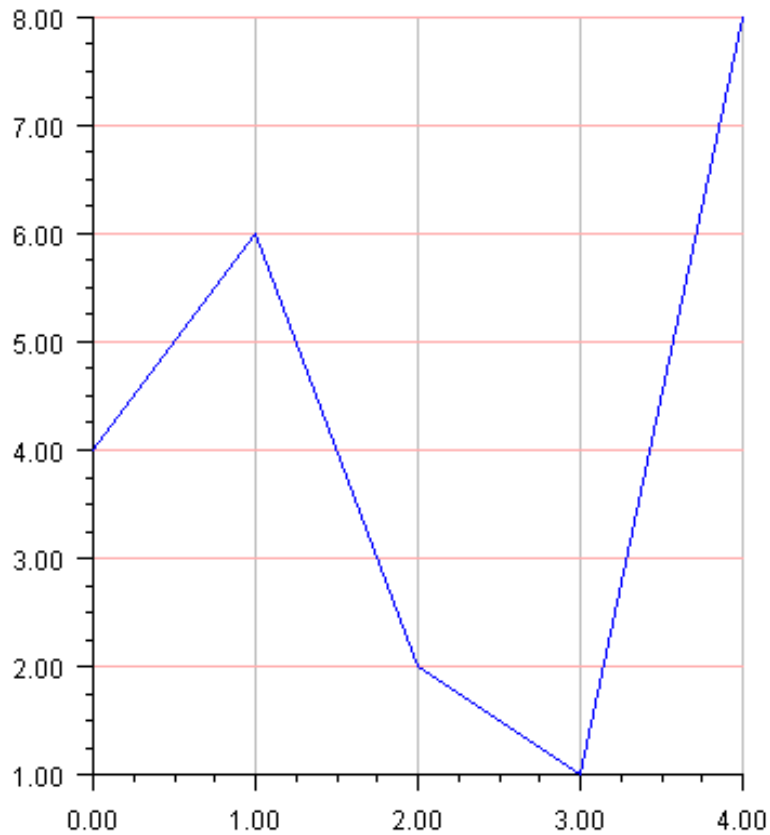
Grid

The [Grid](#) node controls the drawing of grid lines on a chart. The `Grid` is created by [Axis1D](#) as its child. It can be retrieved using the property [Axis1D.Grid](#).

By default, `Grid` nodes are not drawn. To enable them, set their [IsVisible](#) property to `true`. `Grid` nodes control the drawing of the grid lines perpendicular to their parent axis. So the *x*-axis `Grid` node controls the drawing of the vertical grid lines.

Example

In this example, the *x*-axis grid lines are painted light gray and the *y*-axis grid lines are pink.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleGrid : FrameChart {

    public SampleGrid() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        axis.AxisX.Grid.IsVisible = true;
        axis.AxisY.Grid.IsVisible = true;
        axis.AxisX.Grid.LineColor = Color.LightGray;
        axis.AxisY.Grid.LineColor = Color.Pink;

        double[] y = {4, 6, 2, 1, 8};
        Data data = new Data(axis, y);
        data.DataType = Data.DATA_TYPE_LINE;
        data.LineColor = Color.Blue;
    }
}
```

```
public static void Main(string[] argv) {  
    System.Windows.Forms.Application.Run(new SampleGrid());  
}  
}
```

Custom Transform

A custom transformation allows a user-defined mapping of data to an axis. A custom transform is used when the [Transform](#) attribute has the value [TRANSFORM_CUSTOM](#). The custom transform is the value of the `CustomTransform` attribute set with [AbstractChartNode.CustomTransform](#).

A custom transform implements the [Transform](#) interface. This interface has three methods. One, [SetupMapping](#), is called first to allow the transformation to initialize itself. The other two, [MapUserToUnit](#) and [MapUnitToUser](#), specify a mapping from the window interval onto $[0, 1]$. These methods must each be the inverse of the other.

Example: Normal Probability Plot

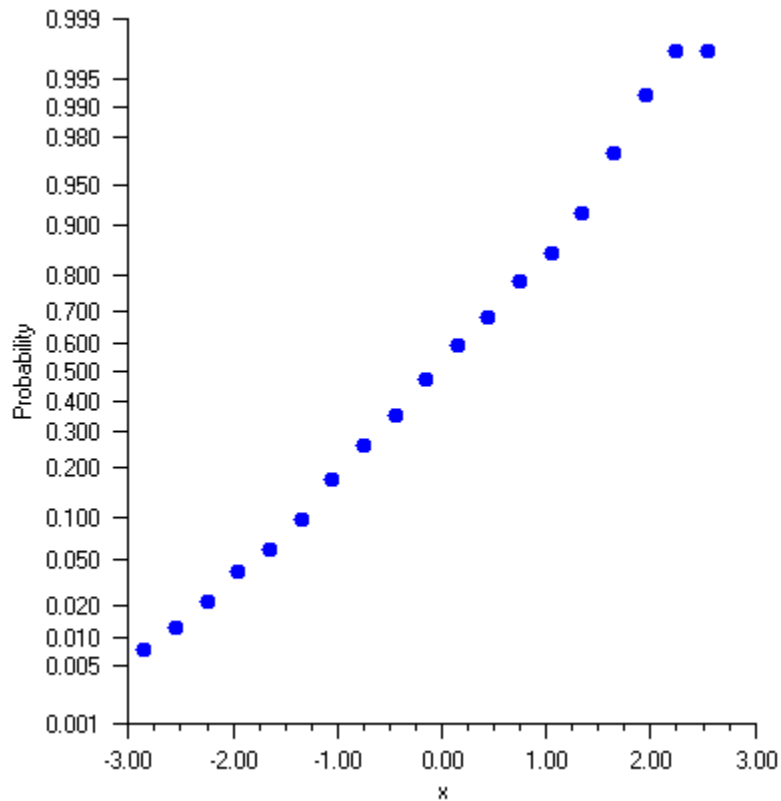
A normal probability plot maps normally distributed data into a straight line, just as a semilog plot maps exponential data into a straight line.

In this example, 400 normally distributed random numbers are grouped into 20 bins. The bin counts are normalized by dividing by the number of samples (400). Cumulative probabilities are computed by summing the probabilities in all of the bins to the left of the current bin.

The custom transformation is the normal cumulative distribution function, [Cdf.Normal](#), and its inverse, [InvCdf.Normal](#), scaled to map the probability range $[0.001, 0.999]$ onto $[0, 1]$.

Autoscaling is turned off on the probability (y) axis and a fixed set of probability tick marks are specified.

The plot is of the bin centered on the x -axis versus the cumulative probabilities on the y -axis. The points are not in an exactly straight line because with only a finite number of samples, the distribution does not exactly match the normal distribution.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using Imsl.Stat;
using System.Drawing;

public class SampleProbability : FrameChart {

    public SampleProbability() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        double[] ticks = {
            0.001, 0.005, 0.01, 0.02, 0.05, 0.10, 0.20, 0.30,
            0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 0.98,
            0.99, 0.995, 0.999};
        double a = ticks[0];
        double b = ticks[ticks.Length-1];

        axis.AxisX.AxisTitle.SetTitle("x");
        axis.AxisY.AxisTitle.SetTitle("Probability");

        axis.AxisY.Transform = Axis.TRANSFORM_CUSTOM;
    }
}
```



```

axis.AxisY.CustomTransform = new NormalTransform();
axis.AxisY.AutoscaleInput = Axis.AUTOSCALE_OFF;
axis.AxisY.SetWindow(a, b);
axis.AxisY.TextFormat = "0.000";
axis.AxisY.SetTicks(ticks);
axis.AxisY.MinorTick.IsVisible = false;

int nSamples = 400;
int nBins = 20;

// Setup the bins
double[] bins = new double[nBins];
double dx = 6.0/nBins;
double[] x = new double[nBins];
for (int k = 0; k < x.Length; k++) {
    x[k] = -3.0 + (k+0.5)*dx;
}

// Generate random normal deviates and sort into bins
Random r = new Random(123457);
for (int k = 0; k < nSamples; k++) {
    double t = r.NextNormal();
    int j = (int)System.Math.Round((t+3.0-0.5*dx)/dx);
    if (j <= 0) {
        bins[0]++;
    } else if (j >= nBins-1) {
        bins[nBins-1]++;
    } else {
        bins[j]++;
    }
}

// Compute the cumulative distribution
// y[k] is the sum of bins[j] for j=0,...,k divided by the nSamples.
double[] y = new double[nBins];
y[0] = bins[0]/nSamples;
for (int k = 1; k < nBins; k++) {
    y[k] = y[k-1] + bins[k]/nSamples;
}

// Plot the data using markers
Data data = new Data(axis, x, y);
data.DataType = Data.DATA_TYPE_MARKER;
data.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
data.MarkerColor = Color.Blue;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleProbability());
}
}

class NormalTransform : Transform
{

```

```

private double scaleA, scaleB;

// Initializes the mappings between user and coordinate space.
public void SetupMapping(Axis1D axis1d)
{
    double[] w = axis1d.GetWindow();
    double t = InvCdf.Normal(w[0]);
    scaleB = 1.0 / (InvCdf.Normal(w[1]) - t);
    scaleA = -scaleB * t;
}

// Maps a point in [0,1] to a probability.
public double MapUnitToUser(double unit)
{
    return Cdf.Normal((unit - scaleA) / scaleB);
}

// Maps a probability to the interval [0,1].
public double MapUserToUnit(double p)
{
    return scaleA + scaleB * InvCdf.Normal(p);
}
}

```

Multiple Axes

An IMSL C# Numerical Library chart can contain any number of axes. Each axis has its own mapping from the user coordinates to the device (screen) coordinates.

Normally, the x -axis is at the bottom of the chart and the y -axis is to the left. The attribute `Type` can be changed to move the x -axis to the top of the chart and/or the y -axis to the right of the chart.

Axis can be moved from the chart edge, either away from the chart or into the middle of the chart data area, by setting the attribute `Cross`.

Attribute Type

The attribute `Type` specifies the position of an x or y -axis. [Axis1D.Type](#) should be used to set the axis type. Applied to the x -axis it can have the values [AXIS_X](#) (the default) or [AXIS_X_TOP](#). Applied to the y -axis, it can have the value [AXIS_Y](#) (the default) or [AXIS_Y_RIGHT](#).

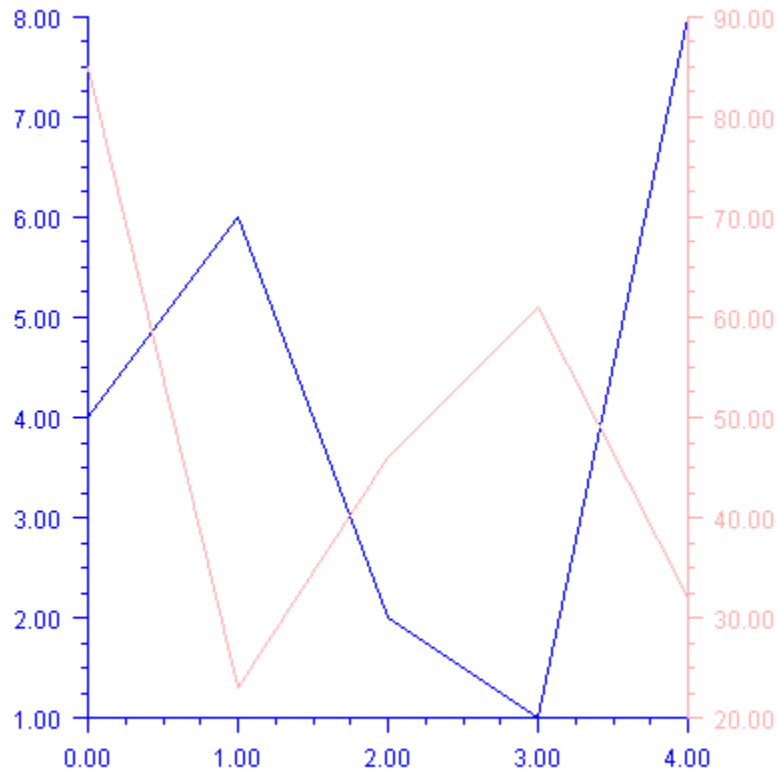
Attribute Cross

The `Cross` attribute specifies the coordinates of the intersection of the x -axis and y -axis. [AxisXY.SetCross](#) should be used to set the coordinates. This can be inside or outside of the chart body. `Cross` can be used to place multiple y -axes to the left of the chart or multiple x -axes below the chart.

Example

Two data sets are plotted, each on its own axis. The first (blue) axis is left in the default position with the y -axis on the left. The second (pink) axis has its y -axis moved to the left.

In this example the x -axis is shared between the two axes, so it is not painted as part of the second (pink) axis. This is done by setting its `IsVisible` property attribute to `false`.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using System.Drawing;  
  
public class SampleAxesLeftRight : FrameChart {  
  
    public SampleAxesLeftRight() {  
        Chart chart = this.Chart;  
  
        AxisXY axisLeft = new AxisXY(chart);  
        double[] yLeft = {4, 6, 2, 1, 8};  
        Data dataLeft = new Data(axisLeft, yLeft);  
        dataLeft.DataType = Data.DATA_TYPE_LINE;  
        axisLeft.LineColor = Color.Blue;  
        axisLeft.TextColor = Color.Blue;  
    }  
}
```

```

    AxisXY axisRight = new AxisXY(chart);
    axisRight.AxisX.IsVisible = false;
    axisRight.AxisY.Type = Axis1D.AXIS_Y_RIGHT;
    double[] yRight = {85, 23, 46, 61, 32};
    Data dataRight = new Data(axisRight, yRight);
    dataRight.DataType = Data.DATA_TYPE_LINE;
    axisRight.LineColor = Color.Pink;
    axisRight.TextColor = Color.Pink;
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(
        new SampleAxesLeftRight());
}
}

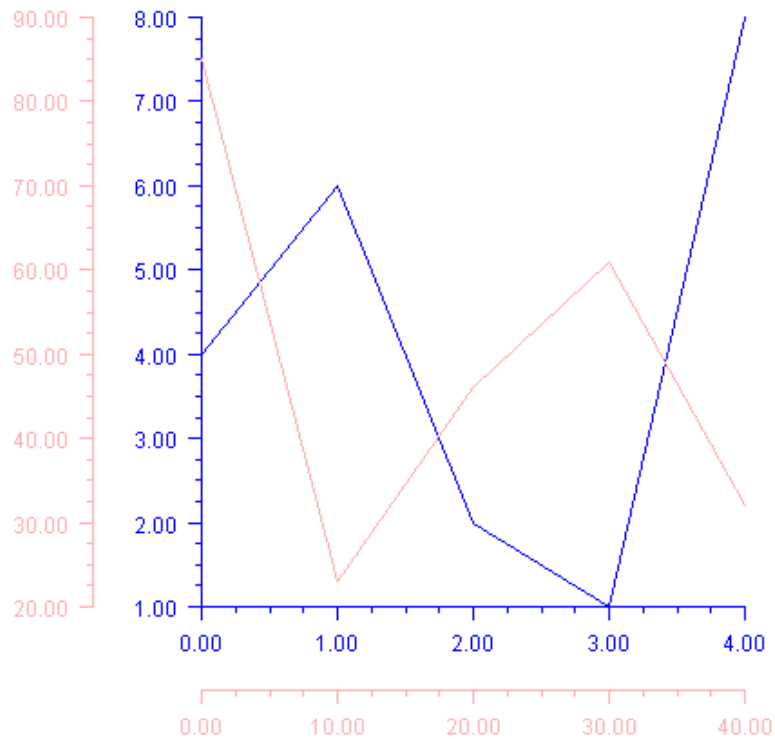
```

Cross Example

Multiple x and y -axes are shown.

The `Cross` attribute is used to specify that the second (pink) axes intersect at $(-8,10)$, in the pink-axis coordinate system.

The `Viewport` attribute is changed in both sets of axes to shrink the size of the chart body and leave more room to the left and below the chart for the pink axes.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleAxesCross : FrameChart {

    public SampleAxesCross() {
        Chart chart = this.Chart;

        AxisXY axisLeft = new AxisXY(chart);
        double[] yLeft = {4, 6, 2, 1, 8};
        Data dataLeft = new Data(axisLeft, yLeft);
        dataLeft.DataType = Data.DATA_TYPE_LINE;
        axisLeft.LineColor = Color.Blue;
        axisLeft.TextColor = Color.Blue;

        AxisXY axisRight = new AxisXY(chart);
        axisRight.SetCross(-8, 10);
        double[] xRight = {0, 10, 20, 30, 40};
        double[] yRight = {85, 23, 46, 61, 32};
        Data dataRight = new Data(axisRight, xRight, yRight);
    }
}
```

```

    dataRight.DataType = Data.DATA_TYPE_LINE;
    axisRight.LineColor = Color.Pink;
    axisRight.TextColor = Color.Pink;

    double[] viewport = {0.3, 0.9, 0.05, 0.7};
    axisLeft.SetViewport(viewport);
    axisRight.SetViewport(viewport);
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleAxesCross());
}
}

```

Background

[Background](#) controls the drawing of the chart's background. It is created by [Chart](#) as its child. It can be retrieved from a [Chart](#) object using the [Chart.Background](#) property.

The fill area attributes in the [Background](#) node determine how the background is drawn (see "[Fill Area Attributes](#)" on page 111).

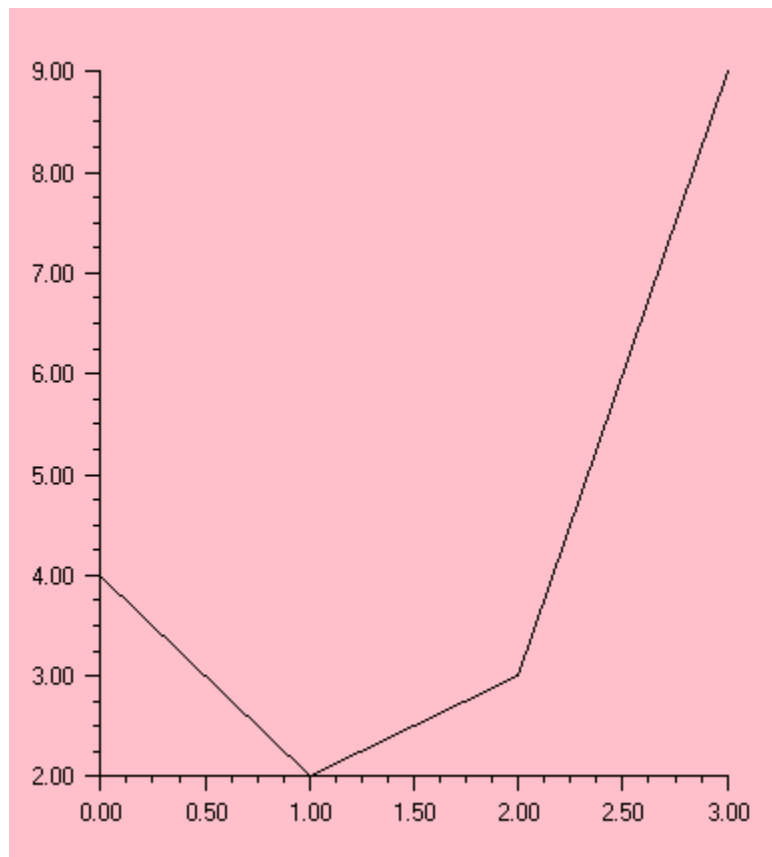
The attribute [FillType](#) has the global default value of [FILL_TYPE_SOLID](#). The attribute [FillColor](#) attribute is set to [Color.White](#) in this node.

Solid Color Background

To set the background to a solid color:

- set the attribute [FillType](#) to [FILL_TYPE_SOLID](#), and
- set the attribute [FillColor](#) to the desired color.

For example the following code sets the background to pink. To view chart in color please see the online documentation.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleBackgroundSolid : FrameChart {

    public SampleBackgroundSolid() {
        Chart chart = this.Chart;
        chart.Background.FillType = ChartNode.FILL_TYPE_SOLID;
        chart.Background.FillColor = Color.Pink;
        AxisXY axis = new AxisXY(chart);
        double[] y = {4, 2, 3, 9};
        new Data(axis, y);
    }

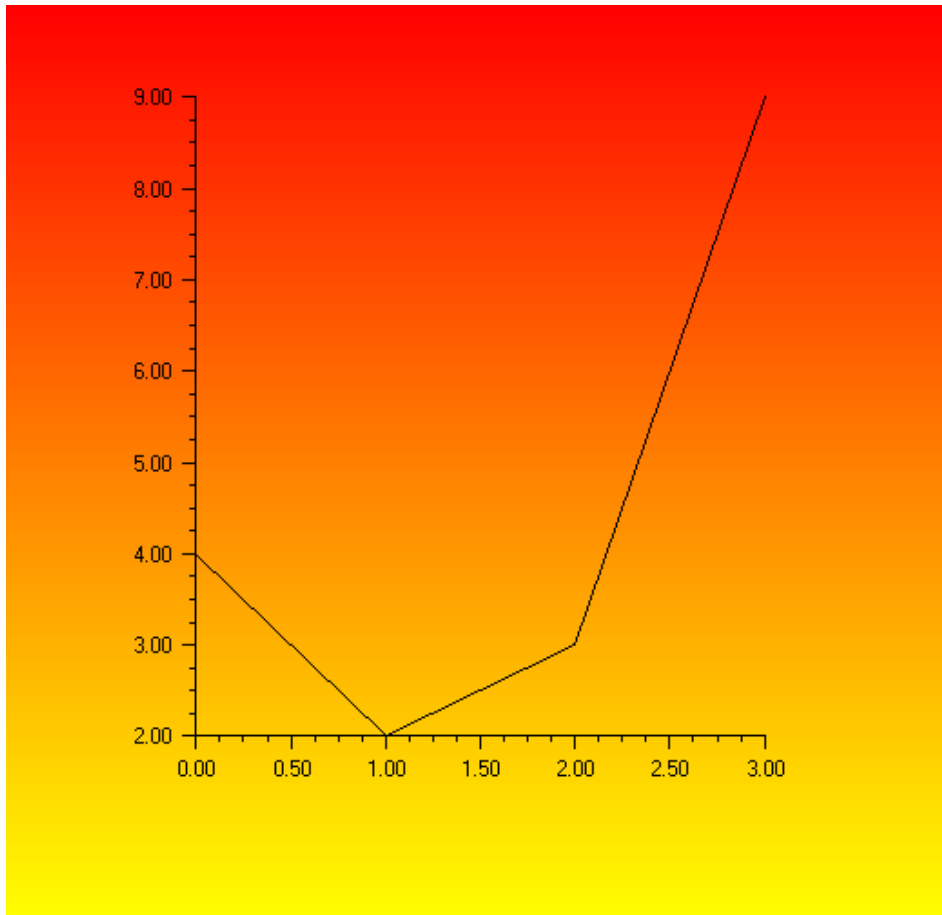
    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleBackgroundSolid());
    }
}
```

Gradient Color Background

To set the background to a color gradient:

- set the attribute `FillType` to `FILL_TYPE_GRADIENT`, and
- set the attribute `Gradient` to the desired color gradient specification.

For example the following code uses a yellow-to-red vertical gradient for the background setting. See “[Fill Area Attributes](#)” on page 111 for more information on gradients.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using System.Drawing;  
  
public class SampleBackgroundGradient : FrameChart {  
  
    public SampleBackgroundGradient() {  
        Chart chart = this.Chart;  
        chart.Background.FillType = ChartNode.FILL_TYPE_GRADIENT;  
    }  
}
```



```

        chart.Background.SetGradient(Color.Yellow, Color.Yellow,
            Color.Red, Color.Red);
        AxisXY axis = new AxisXY(chart);
        double[] y = {4, 2, 3, 9};
        new Data(axis, y);
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(
            new SampleBackgroundGradient());
    }
}

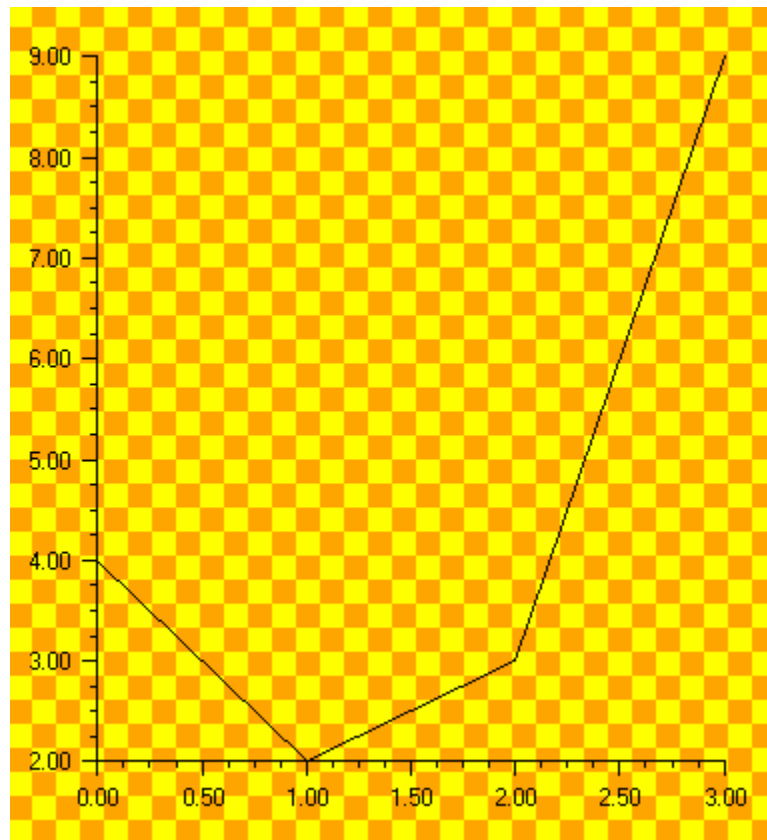
```

Pattern Background

To set the background to a color pattern:

- set the attribute [FillType](#) to [FILL_TYPE_PAINT](#), and
- set the attribute “[FillPaint](#)” on page 113 to the desired pattern.

For example the following code sets the background to yellow/orange checkerboard pattern. See “[Fill Area Attributes](#)” on page 111 for more information on patterns.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleBackgroundPaint : FrameChart {

    public SampleBackgroundPaint() {
        Chart chart = this.Chart;
        chart.Background.FillType = ChartNode.FILL_TYPE_PAINT;
        Brush brush = FillPaint.Checkerboard(
            24, Color.Yellow, Color.Orange);
        chart.Background.SetFillPaint(brush);
        AxisXY axis = new AxisXY(chart);
        double[] y = {4, 2, 3, 9};
        new Data(axis, y);
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(
            new SampleBackgroundPaint());
    }
}
```

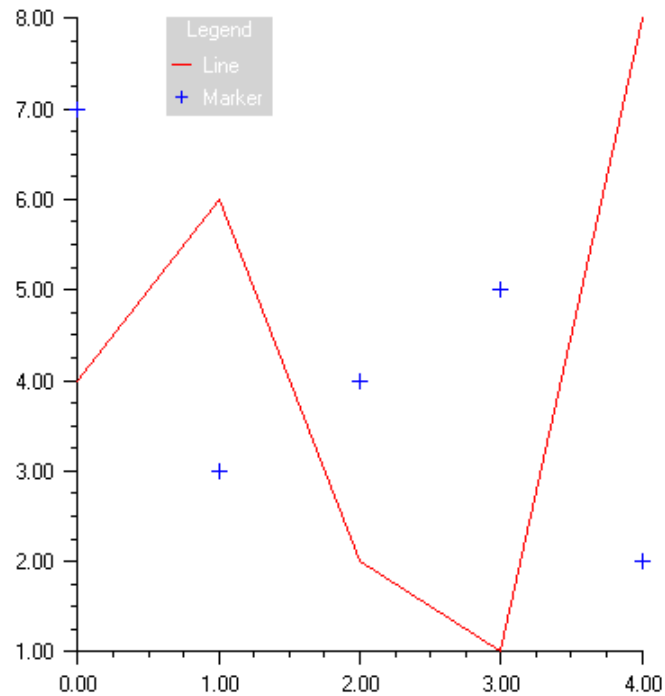
Legend

The legend is used to identify data sets. [Data](#) nodes that have their `Title` attribute defined are automatically included in the legend box.

The [Legend](#) node is automatically created by the [Chart](#) node as its child. By default, the Legend is not drawn because its [IsVisible](#) property is set to `false`.

Simple Legend Example

At a minimum, adding a legend to a chart requires setting the legend's [IsVisible](#) property to `true` and setting the `Title` attribute in the `Data` nodes that are to appear in the legend box. This example shows such a minimal legend.



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleSimpleLegend : FrameChart {

    public SampleSimpleLegend() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        chart.Legend.IsVisible = true;

        double[] y1 = new double[] {4, 6, 2, 1, 8};
        Data data1 = new Data(axis, y1);
        data1.DataType = Data.DATA_TYPE_LINE;
        data1.LineColor = Color.Red;
        data1.SetTitle("Line");

        double[] y2 = new double[] {7, 3, 4, 5, 2};
        Data data2 = new Data(axis, y2);
    }
}
```

```

        data2.DataType = Data.DATA_TYPE_MARKER;
        data2.MarkerColor = Color.Blue;
        data2.SetTitle("Marker");
    }

    public static void Main(string[] argv) {
        System.Windows.Forms.Application.Run(new SampleSimpleLegend());
    }
}

```

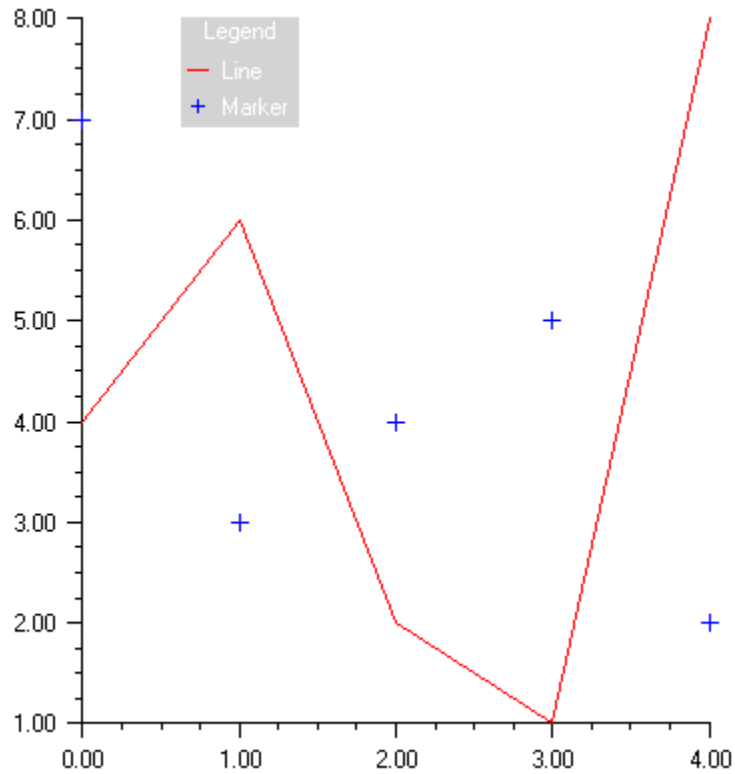
Legend Example

This example shows more of the attributes that affect a legend. If the legend's `Title` attribute is set, then it is used as a header in the legend box.

The text properties for all of the text strings in the legend box are obtained from the `Legend` node, not from the associated `Data` nodes (see "[Text Attributes](#)" on page 114). Here the `TextColor` is set to white.

The background of the legend box can be set by changing the fill attributes (see "[Fill Area Attributes](#)" on page 111). By default in the `Legend` node, `FillType` is set to `FILL_TYPE_NONE` and `FillColor` is set to `Color.LightGray`.

The position of the legend box is controlled by its `viewport` attribute. The viewport is the region of the `Control`, in which the chart is being drawn, that the legend box occupies. The upper left corner is (0,0) and the lower right corner is (1,1). The default value of the legend viewport is [0.83, 0.0] by [0.2, 0.2]. The default value of the legend viewport is [0.83, 0.0] by [0.2, 0.2]. The position of the legend can be controlled by the `xmin` and `ymin` parameters of method [SetViewport](#) (note that the `xmax` and `ymax` parameters do not affect the legend viewport).



[\(Download Code\)](#)

```
using Imsl.Chart2D;
using System.Drawing;

public class SampleLegend : FrameChart {

    public SampleLegend() {
        Chart chart = this.Chart;
        AxisXY axis = new AxisXY(chart);

        Legend legend = chart.Legend;
        legend.IsVisible = true;;
        legend.SetTitle("Legend");
        legend.TextColor = Color.White;
        legend.FillType = Legend.FILL_TYPE_SOLID;
        legend.SetViewport(0.3, 0.4, 0.1, 0.4);

        double[] y1 = new double[] {4, 6, 2, 1, 8};
        Data data1 = new Data(axis, y1);
        data1.DataType = Data.DATA_TYPE_LINE;
        data1.LineColor = Color.Red;
    }
}
```

```

    data1.SetTitle("Line");

    double[] y2 = new double[] {7, 3, 4, 5, 2};
    Data data2 = new Data(axis, y2);
    data2.DataType = Data.DATA_TYPE_MARKER;
    data2.MarkerColor = Color.Blue;
    data2.SetTitle("Marker");
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleLegend());
}
}

```

Colormaps

Colormaps are mappings from [0,1] to colors. They are a one-dimensional parameterized path through the color cube. For an example of their use, see [Heatmap](#).

A number of colormaps are predefined in the [Colormap](#) class. It is also possible to create new custom colormaps.

The predefined colormaps are listed in the table below.

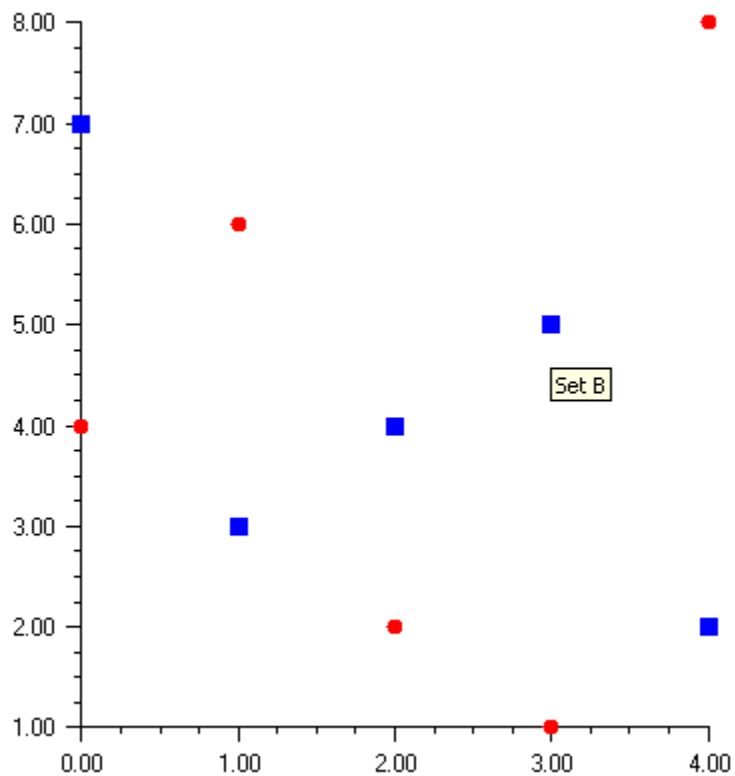
RED	Light red to dark red
GREEN	Light green to dark green
BLUE	Light blue to dark blue
BW_LINEAR	Black and white linear
BLUE_WHITE	Blue/White
GREEN_RED_BLUE_WHITE	Green/Red/Blue/White
RED_TEMPERATURE	Red Temperature
BLUE_GREEN_RED_YELLOW	Blue/Green/Red/Yellow
STANDARD_GAMMA	Standard Gamma
PRISM	Prism
RED_PURPLE	Red/Purple
GREEN_WHITE_LINEAR	Green/White Linear
GREEN_WHITE_EXPONENTIAL	Green/White Exponential
GREEN_PINK	Green/Pink
BLUE_RED	Blue/Red
SPECTRAL	Spectral
WB_LINEAR	White/Black Linear

Tool Tips

Windows.Forms supports tool tips, small help boxes that pop up when the mouse hovers over some element. The [ToolTip](#) node allows tool tips to be associated with chart elements. The text displayed in the tool tip is the `Title` attribute of the `ToolTip`'s parent node.

Example

In this example two [Data](#) nodes are created. Each `Data` node has a `Title` defined and a `ToolTip` node added as a child. Note that the `ToolTip` node just has to be created, no methods using it are normally required.



[\(Download Code\)](#)

```
using Imsl.Chart2D;  
using System.Drawing;  
  
public class SampleToolTip : FrameChart {  
  
    public SampleToolTip() {  
        Chart chart = this.Chart;  
        AxisXY axis = new AxisXY(chart);  
    }  
}
```

```

double[] y1 = new double[] {4, 6, 2, 1, 8};
Data data1 = new Data(axis, y1);
data1.DataType = Data.DATA_TYPE_MARKER;
data1.MarkerColor = Color.Red;
data1.MarkerType = Data.MARKER_TYPE_FILLED_CIRCLE;
data1.SetTitle("Set A");
new ToolTip(data1);

double[] y2 = new double[] {7, 3, 4, 5, 2};
Data data2 = new Data(axis, y2);
data2.DataType = Data.DATA_TYPE_MARKER;
data2.MarkerColor = Color.Blue;
data2.MarkerType = Data.MARKER_TYPE_FILLED_SQUARE;
data2.SetTitle("Set B");
new ToolTip(data2);
}

public static void Main(string[] argv) {
    System.Windows.Forms.Application.Run(new SampleToolTip());
}
}

```


Chapter 5: Actions

IMSL C# Numerical Libraries

IMSL C# Numerical Libraries supports the following actions:

- [“Picking”](#) on page 154
- [“Zoom”](#) on page 156
- [“Printing”](#) on page 161

Picking

The pick mechanism allows [MouseEvent](#)s to be associated with chart nodes. The pick mechanism follows the .NET delegate pattern.

A [PickEventHandler](#) is added to a [ChartNode](#), using the node’s [PickPerformed](#) method and the delegate += syntax to define the method to be called when the event occurs.

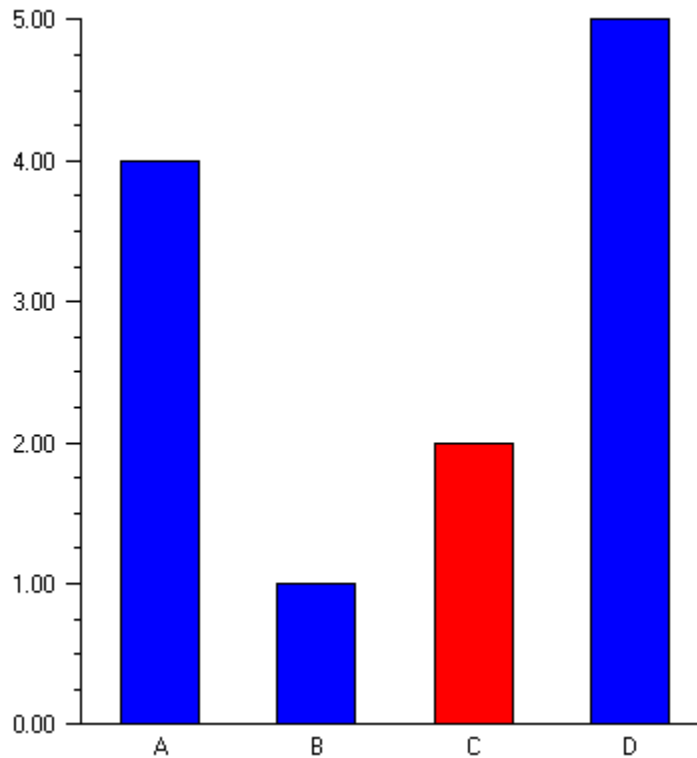
A pick is fired by calling the method [Chart.Pick](#) in the top-level [ChartNode](#). Normally this is done in response to a mouse click. Mouse clicks can be detected by adding a [MouseEventHandler](#) to the [MouseDown](#) property of the chart’s container.

Example

In this example, when a bar is clicked it toggles its color between blue and red.

A [MouseEventHandler](#) is added to the `Panel`, which calls method `Chart.Pick`.

The pick delegate is added to the chart node `bar`. This means that it is active for that node and its children but is not active for the axes and other nodes.



[\(Download Code\)](#)

```
using System.Windows.Forms;
using System.Drawing;
using Imsl.Chart2D;

public class SamplePick : FrameChart
{
    private Chart chart;
    private double[] x = new double[] { 0, 1, 2, 3 };
    private double[] y = new double[] { 4, 1, 2, 5 };

    public SamplePick()
    {
        chart = this.Chart;
        AxisXY axis = new AxisXY(chart);
        Bar bar = new Bar(axis, x, y);
        bar.BarType = Bar.BAR_TYPE_VERTICAL;
        bar.SetLabels(new string[] { "A", "B", "C", "D" });
        bar.FillColor = Color.Blue;

        // Add the event handler delegates
        bar.PickPerformed += new PickEventHandler(SamplePick_PickPerformed);
        this.Panel.MouseDown += new MouseEventHandler(SamplePick_MouseDown);
    }
}
```

```

private void SamplePick_MouseDown(object sender, MouseEventArgs e)
{
    chart.Pick(e);
}

private void SamplePick_PickPerformed(PickEventArgs param)
{
    ChartNode node = param.Node;
    int count = node.GetIntegerAttribute("pick.count", 0);
    count++;
    node.SetAttribute("pick.count", (System.Object) (count));

    // Change the bar's color depending on the number of times
    // it has been picked.
    Color color = ((count % 2 == 0) ? Color.Blue : Color.Red);
    node.FillColor = color;
    Refresh();
}

public static void Main(string[] argv)
{
    System.Windows.Forms.Application.Run(new SamplePick());
}
}

```

Zoom

IMSL C# Numerical Libraries provides the functionality to implement a variety of zoom policies instead of implementing a single specific zoom policy. The following example shows how to build a zoom policy that draws a rubber-band box in a scatter plot and zooms both the x -axis and y -axis to correspond to the region selected. Zoom out is also implemented.

This code can be used as the basis of an implementation of other zoom policies. For example, with a function plot one might want to only change the x -axis in response to a zoom and leave the y -axis alone. In other situations it may be desirable to zoom in or out a fixed amount around the location of a mouse click.

Example

In the constructor:

- A scatter plot is created,
- Zoom items are added to the main menu,
- A [MouseEventHandler](#) is added to the panel. A [FrameChart](#) contains a number of components, including a [Panel](#) in which the chart is drawn. *It is important that the [MouseEventHandler](#) be added to the component in which the chart is drawn, so that the [MouseEventArgs](#) coordinates are the same as the device coordinates of the chart.*

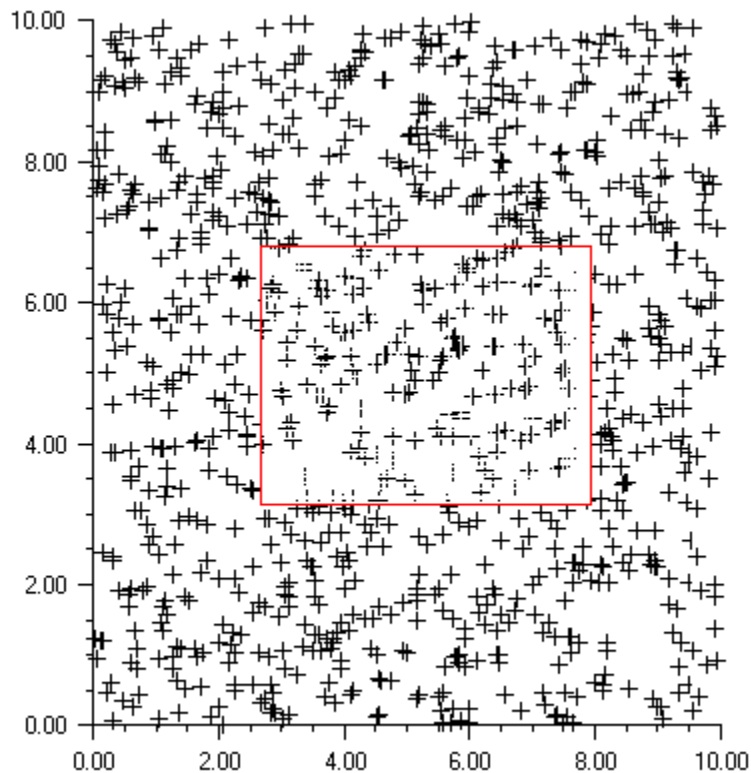
A mouse press event starts the zoom. In response to the event a `MouseEventHandler` is added to the panel to listen for mouse drag events. The location of this initial event is also recorded.

A mouse drag event resizes the area of the zoom. In response, the old rubber-band box is erased and a new box is drawn. The new box has the initial mouse press location as one corner and this drag event location as the opposite corner. The location of this event is stored in `(xLast,yLast)`.

A mouse release event completes the zoom. In response,

- The `MouseEventHandler` for `MouseMove` is removed from the panel,
- The existing `Window` attributes for the *x*-axis and *y*-axis are saved on a stack. They may be used later to zoom out.
- The new `Window` is computed. The `Window` is the range, in user coordinates, along an axis. The method [Axis.MapUserToDevice](#) is used to map the device (pixel) coordinates to the user coordinate space. The new windows are constrained to be inside of the existing window.
- Autoscaling is turned off, so that the new `Window` values will be used without further modification.
- The chart is redrawn with the new windows.

The menu items, added by the constructor to the main menu, can be used to zoom out. The added menu items add an [EventHandler](#) with the `menuItem_Click` delegate as the method called when these menu items are selected. The `menuItem_Click` method implements “Out” by popping previous [Window](#) attribute values off a stack. It implements “Restore” by re-enabling [autoscaling](#).



[\(Download Code\)](#)

```
using System;
using System.Windows.Forms;
using System.Drawing;
using Imsl.Chart2D;

public class SampleZoom : FrameChart
{
    private Panel panel;
    private AxisXY axis;
    private int xFirst, yFirst;
    private int xLast, yLast;
    private System.Collections.Stack stack;
    private MouseEventHandler mouseMoveHandler;

    public SampleZoom()
    {
        panel = this.Panel;
        Chart chart = this.Chart;
        axis = new AxisXY(chart);
        int n = 1000;
        double[] x = new double[n];
        double[] y = new double[n];
        Random ran = new Random();
```

```

for (int k = 0; k < n; k++) {
    x[k] = 10.0 * ran.NextDouble();
    y[k] = 10.0 * ran.NextDouble();
}
Data data = new Data(axis, x, y);
data.DataType = Data.DATA_TYPE_MARKER;

// add menu "Zoom" menu
MenuItem menuZoom = new MenuItem();
menuZoom.Text = "&Zoom";
menuZoom.Shortcut = Shortcut.CtrlZ;
AddMenuItem(menuZoom, "Out", Shortcut.CtrlO);
AddMenuItem(menuZoom, "Restore", Shortcut.CtrlR);
this.Menu.MenuItems.Add(menuZoom);

// save x-axis and y-axis Window attributes on this stack.
// they are used to zoom out one level.
stack = new System.Collections.Stack();

// listen for mouse press events
panel.MouseDown += new MouseEventHandler(Panel_MouseDown);
panel.MouseUp += new MouseEventHandler(Panel_MouseUp);

        mouseMoveHandler = new MouseEventHandler(panel_MouseMove);
}

// Add a menu item
private void AddMenuItem(MenuItem menuZoom, string title,
    Shortcut sc)
{
    MenuItem menuItem = new MenuItem(title);
    menuItem.Text = title;
    menuItem.Shortcut = sc;
    menuZoom.MenuItems.Add(menuItem);
    menuItem.Click += new EventHandler(menuItem_Click);
}

// A mouse press starts the zoom
// Record location of this point and listen for drag (motion) events.
void Panel_MouseDown(object sender, MouseEventArgs e)
{
    xFirst = xLast = e.X;
    yFirst = yLast = e.Y;
    panel.MouseMove += mouseMoveHandler;
}

// Releasing the mouse button ends the zoom
// Stop listening for move events and update the Window attributes
void Panel_MouseUp(object sender, MouseEventArgs e)
{
    panel.MouseMove -= mouseMoveHandler;

    // ignore degenerate zooms
    if (xFirst == xLast || yFirst == yLast)
    {

```

```

        Refresh();
        return;
    }

    // get window and convert to user coordinates
    double[] windowX = (double[])axis.AxisX.GetWindow();
    double[] windowY = (double[])axis.AxisY.GetWindow();

    // save the windows on the stack (for zoom out option)
    stack.Push(windowX);
    stack.Push(windowY);

    // get user coordinate of left-upper corner of the box
    // limit it to stay inside current window
    double[] boxLU = new double[2];
    int x = Math.Min(xFirst, xLast);
    int y = Math.Min(yFirst, yLast);
    axis.MapDeviceToUser(x, y, boxLU);

    // get user coordinate of right-lower corner of the box
    // limit it to stay inside current window
    double[] boxRL = new double[2];
    x = Math.Max(xFirst, xLast);
    y = Math.Max(yFirst, yLast);
    axis.MapDeviceToUser(x, y, boxRL);

    // set axis window to range of rubber-band box
    // and disable autoscale to force use of window settings
    axis.AutoscaleInput = ChartNode.AUTOSCALE_OFF;
    double xa = Math.Max(windowX[0], boxLU[0]);
    double xb = Math.Min(windowX[1], boxRL[0]);
    double ya = Math.Max(windowY[0], boxRL[1]);
    double yb = Math.Min(windowY[1], boxLU[1]);
    axis.AxisX.SetWindow(xa, xb);
    axis.AxisY.SetWindow(ya, yb);

    // force redraw of the chart
    Refresh();
}

// Moving the mouse after a click continues the zoom.
// Erase the old rubber band box and draw a new one
// Also keep track of the location of this event
void panel_MouseMove(object sender, MouseEventArgs e)
{
    // erase previous rectangle
    Graphics g = panel.CreateGraphics();
    DrawBox(g, Color.White);

    // draw new rectangle
    xLast = e.X;
    yLast = e.Y;
    DrawBox(g, Color.Red);
}

```



```

// Draw a box with (xFirst, yFirst) and (xLast, yLast) as its corners
private void DrawBox(Graphics g, Color color)
{
    int x = Math.Min(xFirst, xLast);
    int y = Math.Min(yFirst, yLast);
    int w = Math.Abs(xLast - xFirst);
    int h = Math.Abs(yLast - yFirst);
    g.DrawRectangle(new Pen(color), x, y, w, h);
}

void menuItem_Click(object sender, EventArgs e)
{
    string cmd = ((MenuItem)sender).Text;
    if (cmd.Equals("Out"))
    {
        try
        {
            // zoom out by restoring window settings from the stack
            axis.AxisY.SetWindow((double[])stack.Pop());
            axis.AxisX.SetWindow((double[])stack.Pop());
        }
        catch (System.InvalidOperationException)
        {
            // no more levels to zoom out
            // restore original setting by turning on autoscale
            axis.AutoscaleInput = ChartNode.AUTOSCALE_DATA;
        }
    }
    else if (cmd.Equals("Restore"))
    {
        // restore original setting by turning on autoscale an
        // empty stack
        axis.AutoscaleInput = ChartNode.AUTOSCALE_DATA;
        stack.Clear();
    }
    // force redraw of the chart
    Refresh();
}

public static void Main(string[] argv)
{
    System.Windows.Forms.Application.Run(new SampleZoom());
}
}

```

Printing

Printing from FrameChart

The [FrameChart](#) class, used to build most of the examples in this manual, includes a print option under the file menu. This option prints the chart as large as possible, without distortion, and centered on the page.

Printable Interface

Class [Chart](#) implements the .NET [PrintPage](#) interface, which is used to print a single page. It is implemented by the class `Chart`. The following code fragment shows how to print a chart using its [PrintDocument](#) class and its [PrintPage](#) event.

```
public void Print() {
    PrintDocument printJob = new PrintDocument();
    printJob.PrintPage +=
        new PrintPageEventHandler(Chart.PrintGraphics);
    PrintDialog printDialog = new PrintDialog();
    if (printDialog.ShowDialog() == DialogResult.OK) {
        printJob.Print()
    }
}
```


Appendix A: Web Server Application

An IMSL C# Numerical Libraries chart can be integrated into an ASP.NET application through the [WebChart](#) component. The `WebChart` class extends [System.Web.UI.WebControls.Panel](#) and can be added to an ASP.NET application like any other web control.

There are two sides to an ASP.NET application - the user interface and the code-behind class file. The user interface is often created visually with Visual Studio with the HTML code generated automatically. The code-behind class file is compiled into an assembly that is deployed with the web pages. The following example was generated using Visual Studio 2005. The method applies to other versions of Visual Studio though the code may be different in the details. The code-behind class file is written in C# like the other examples in this document.

The following code was automatically generated by Visual Studio by dragging a `WebChart` onto the page from the Toolbox containing web controls. The `WebChart` control can be added to the Toolbox by using the Add Items... dialog and browsing to the IMSL C# Numerical Libraries assembly, `ImslCS.dll`. Notice the reference to a `WebChart` object. This is the object that will be referenced from the code-behind class file.

```
<%@ Page Language="C#" AutoEventWireup="true" CodeBehind="Default.aspx.cs"
    Inherits="WebApplication1._Default" %>

<%@ Register assembly="ImslCS" namespace="Imsl.Chart2D" tagprefix="ccl" %>

<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Transitional//EN"
    "http://www.w3.org/TR/xhtml1/DTD/xhtml1-transitional.dtd">

<html xmlns="http://www.w3.org/1999/xhtml" >
<head runat="server">
    <title>Untitled Page</title>
</head>
<body>
    <form id="form1" runat="server">
        <div>

            <ccl:WebChart ID="WebChart1" runat="server" Height="240px"
                Width="240px">
            </ccl:WebChart>

        </div>
    </form>
</body>
```

</html>

For this basic example, the chart is created in the `Page_Load` method. The [Chart](#) object is obtained from the `WebChart` and the chart is configured in a manner similar to the desktop form examples. All chart types and most functionality of the IMSL C# Numerical Libraries is available through the `WebChart` control.

[\(Download Code\)](#)

```
using System;
using System.Data;
using System.Configuration;
using System.Web;
using System.Web.Security;
using System.Web.UI;
using System.Web.UI.WebControls;
using System.Web.UI.WebControls.WebParts;
using System.Web.UI.HtmlControls;
using Imsl.Chart2D;

public partial class _Default : System.Web.UI.Page
{
    protected void Page_Load(object sender, EventArgs e)
    {
        Chart chart = WebChart1.Chart;
        AxisXY axis = new AxisXY(chart);
        Data data = new Data(axis, new double[] {5,7,4,1,8});
        data.DataType = ChartNode.DATA_TYPE_LINE |
ChartNode.DATA_TYPE_MARKER;
        data.MarkerType = ChartNode.MARKER_TYPE_FILLED_SQUARE;
        data.MarkerColor = System.Drawing.Color.Red;
        data.LineColor = System.Drawing.Color.Green;
    }
}
```

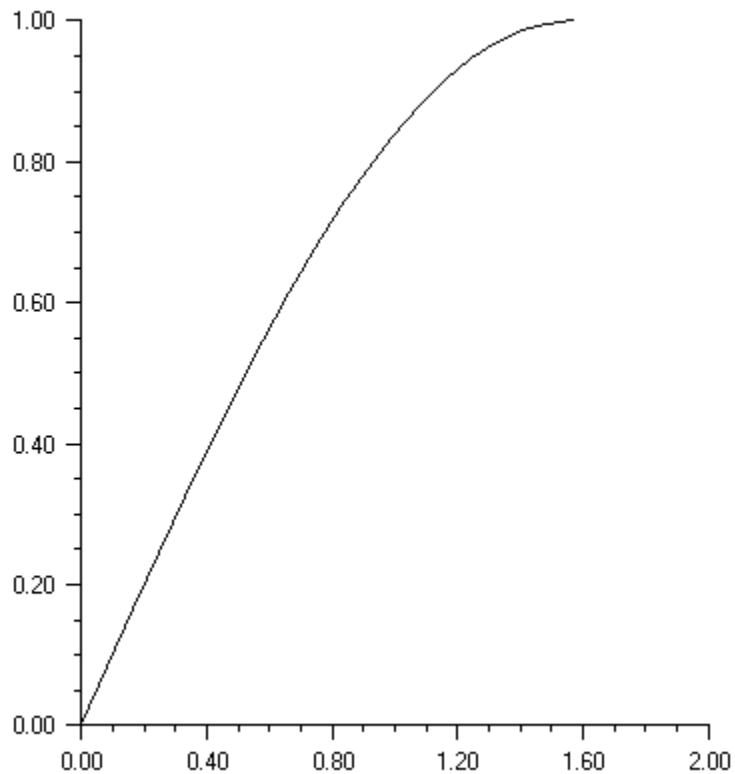
Appendix B: Writing a Chart as a Bitmap Image

Using the ImageIO class

An IMSL C# Numerical Libraries chart can be saved as an image file using the .NET [Image](#) class.

The chart tree is constructed in the usual manner. Here a method called `CreateChart` is used to create a simple chart, with the null-argument [Chart](#) constructor. The chart is written to a file without being displayed using the [Chart.WritePNG](#) method. This method does not require a desktop GUI application using `Windows.Forms`, but can be run in a “headless” mode.

If a chart is being displayed, a [Bitmap](#) object can be created using the [Chart.PaintImage](#) method. This object can then be used like any other .NET Image, including calling its [Save](#) method as in this example. For the `Image` returned by `PaintImage` not to be null, the chart must have been rendered to the screen. Therefore, this method is not suitable for headless applications.



[\(Download Code\)](#)

```
using System;
using System.Drawing;
using System.IO;
using Imsl.Chart2D;

public class SampleImageIO : FrameChart
{
    public SampleImageIO()
    {
        this.Chart = CreateChart();
        // Create an image file from the chart's image once displayed
        Bitmap bmap = new Bitmap(this.Chart.PaintImage());
        bmap.Save("SampleImageIO2.png",
            System.Drawing.Imaging.ImageFormat.Png);
    }

    static Chart CreateChart() {
        Chart chart = new Chart();
        AxisXY axis = new AxisXY(chart);
    }
}
```

```

    int npoints = 20;
    double dx = .5 * Math.PI/(npoints-1);
    double[] x = new double[npoints];
    double[] y = new double[npoints];

    // Generate some data
    for (int i = 0; i < x.Length; i++)
    {
        x[i] = i * dx;
        y[i] = Math.Sin(x[i]);
    }
    new Data(axis, x, y);
    return chart;
}

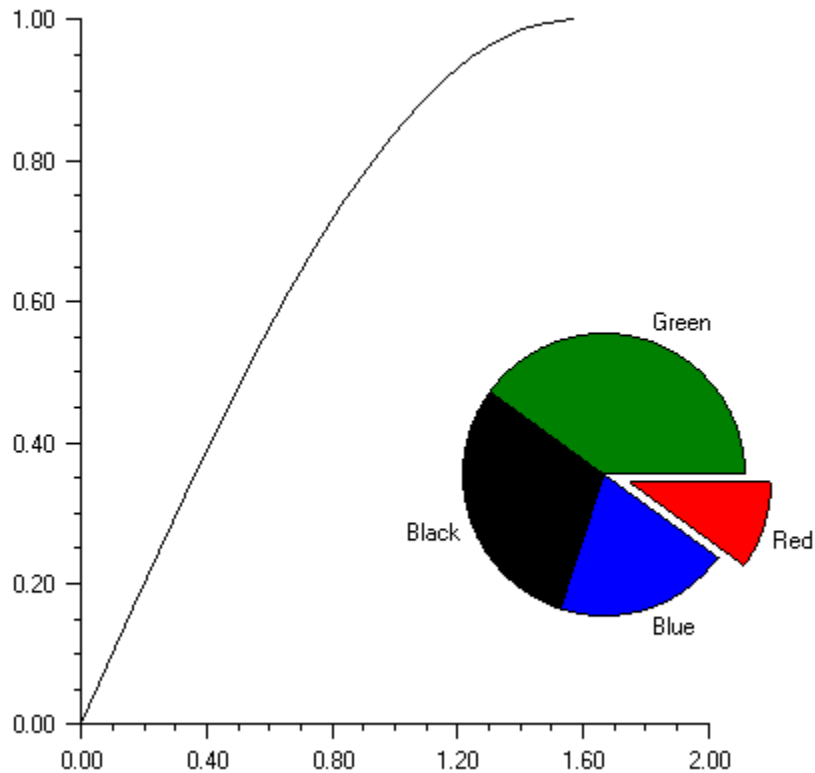
public static void Main(string[] argv)
{
    // Create an image file using WritePNG without a display
    Chart chart = CreateChart();
    chart.ScreenSize = new Size(500, 500);
    FileStream fs =
        new FileStream("SampleImageIO.png", FileMode.OpenOrCreate);
    chart.WritePNG(fs, 500, 500);

    System.Windows.Forms.Application.Run(new SampleImageIO());
}
}

```


Appendix C: Picture-in-Picture

The picture-in-picture effect can be obtained by using the [Viewport](#) attribute. This sets the fraction of the screen into which the chart is to be drawn. The `viewport` attribute's value is a `double[4]` containing $\{x_{min}, x_{max}, y_{min}, y_{max}\}$, on a $[0,1]$ by $[0,1]$ grid with $(0,0)$ at the top-left.



This chart tree for the above picture consists of a chart with an [AxisXY](#) child and a [Pie](#) child. (The `Pie` class is a subclass of [Axis](#).) The [Viewport](#) attribute of the `Pie` node is set to a non-default value.

[\(Download Code\)](#)

```
using System;
using System.Windows.Forms;
using System.Drawing;
using Imsl.Chart2D;

public class SamplePnP : FrameChart
{
    public SamplePnP()
    {
        Chart chart = this.Chart;
        CreateLineChart(chart);
        CreatePieChart(chart);
    }

    private void CreateLineChart(Chart chart) {
        AxisXY axis = new AxisXY(chart);

        int npoints = 20;
        double dx = 0.5 * Math.PI/(npoints-1);
        double[] x = new double[npoints];
        double[] y = new double[npoints];
        for (int i = 0; i < x.Length; i++){
            x[i] = i * dx;
            y[i] = Math.Sin(x[i]);
        }
        new Data(axis, x, y);
    }

    private void CreatePieChart(Chart chart) {
        double[] y = new double[] {10, 20, 30, 40};
        Pie pie = new Pie(chart, y);
        pie.LabelType = Pie.LABEL_TYPE_TITLE;
        pie.SetViewport(0.5, 0.9, 0.3, 0.8);

        PieSlice[] slice = pie.GetPieSlice();

        slice[0].SetTitle("Red");
        slice[0].FillColor = Color.Red;
        slice[0].Explode = 0.2;

        slice[1].SetTitle("Blue");
        slice[1].FillColor = Color.Blue;

        slice[2].SetTitle("Black");
        slice[2].FillColor = Color.Black;

        slice[3].SetTitle("Green");
        slice[3].FillColor = Color.Green;
    }

    public static void Main(string[] argv)
    {
        System.Windows.Forms.Application.Run(new SamplePnP());
    }
}
```

```
} }
```


Index

A

- annotation 119
- applications, adding charts to 9
- Attribute Control Chart
 - CChart 67, 89
 - NpChart 67, 87
 - PChart 67, 84
 - UChart 67, 92
- axis
 - crossed 140
 - layout 122
 - limits 124
 - setting 121
 - tick marks 124
 - titles 126
 - custom tranformation of
 - axes 135
 - units 129
 - tick marks
 - tick marks 131
- axis3d
 - labels
 - for axes 126
 - labels 126

B

- background
 - color 142
- gradient background color
 - gradient
 - gradient 144
- bar
 - charts
 - stacked and grouped
- bar
 - stacked and grouped 45
- bar charts
 - spacing bars
 - bar
- spacing 44
 - width of bars in

- bar
- width 44
- legends
 - legends for
 - legends for 47

C

- candlestick charts
 - plots
 - candlestick
 - candlestick 34
- CChart 89
- charts
 - bar
 - simple
 - simple 42
 - bar 42
 - grouped bar;grouped bar charts
 - grouped 44
 - CuSum 67
 - pie 37
- contour
 - contour 48
- heatmap
 - heatmap 50
- histograms
 - histogram 54
- labels
 - labels for
 - labels for 117
- background
 - background 142
- colormaps 150
- Control Chart
 - Attribute Control Chart
 - CChart 89
 - NpChart 87
 - PChart 84
 - UChart 92
 - Variables Control Chart
 - ControlLimit 68
 - EWMA 67, 96
 - Shewhart Control Charts 67
 - XbarR 78
 - XbarS 70
 - XmR 82
- Cumulative Probability 104
- CuSum 98
 - cumulative sum chart 98
- CuSumStatus 100

D

data point labels 117

E

error bar plots
plots
error bar 27
EWMA 96

F

fills 111, 144, 145
colored 112
tiled
patterned
fills 113
gradient 112
images for 114
outline colors for 112
outlines for 111
types of 112

G

graphs
spline 23

H

popups;tool tips 151

I

implicit nodes 6
Individuals Control Charts
XmR 82

L

labels
string 126
labels3d
dates in 126
legends 146
line
color 108
width 108
grid lines
grid 133

M

marker
color 110
patterns 111
size 110
thickness 111
type 109
chaining method calls 7
mixed error bar plots
plots
mixer error bar 30
picking 154
multiple axes 138

N

normal distribution histograms 54
Normal Probability Plot 104, 135
NpChart 87

P

ParetoChart 102
pattern
background
pattern 145
PChart 84
plots
line and marker;line and marker
plots;marker plots
marker 17
function plot
function
function 21
plots
log
semilog;semilog plot 24
plots
loglog 26
horizontal error bar plots
horizontal error bar 29
plots
high-low-close;high-low-close
plots
high-low-close 32
plots
box 40
plots
polar 56
dendrogram charts
dendrogram 59
printing 161
Probability Plot 104

R

- random values 14
- RChart 78
- reference lines 21
- MS.NET Framework SDK 4

S

- scaling
 - automatic 125, 131
 - input values 125
 - output values 125
- SChart 70
- Shewhart Control Charts
 - ControlLimit 68
 - ShewhartControlChart 67
 - XbarR 78
 - XbarS 70

T

- text 114
 - fonts 114
 - size 115
 - style 115
 - typeface 114
- density, of tick marks 124
- titles
 - axis
 - titles 126
 - plot
 - titles for
- titles for 119

U

- UChart 92
- image files;bitmaps;using for image files; 109, 166

V

- Variables Control Chart
 - EWMA 96
 - Shewhart Control Charts
 - ControlChartLimit 68
 - ShewhartControlChart 67
 - XbarR 78
 - XbarS 70
 - XmR 82
- vertical error bar plots
 - plots
 - vertical error bar 27

- viewport attribute 170

W

- WECO 67
- weekends
 - skipping
 - weekends 126

X

- XbarR 78
- XbarS 70
- XmR 82

Z

- zooming 156