MATLAB® 7
Getting Started Guide

MATLAB®

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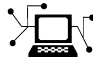

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MATLAB® Getting Started Guide

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Contents

1 Introduction

Product Overview **1-2**
Overview of the MATLAB Environment **1-2**
The MATLAB System **1-3**

Documentation **1-5**

Starting and Quitting the MATLAB Program **1-7**
Starting a MATLAB Session **1-7**
Quitting the MATLAB Program **1-8**

2 Matrices and Arrays

Matrices and Magic Squares **2-2**
About Matrices **2-2**
Entering Matrices **2-4**
sum, transpose, and diag **2-5**
Subscripts **2-7**
The Colon Operator **2-8**
The magic Function **2-9**

Expressions **2-11**
Variables **2-11**
Numbers **2-12**
Operators **2-13**
Functions **2-13**
Examples of Expressions **2-15**

Working with Matrices **2-16**
Generating Matrices **2-16**

The load Function 2-17
M-Files 2-17
Concatenation 2-18
Deleting Rows and Columns 2-19

More About Matrices and Arrays **2-20**
Linear Algebra 2-20
Arrays 2-24
Multivariate Data 2-26
Scalar Expansion 2-27
Logical Subscripting 2-27
The find Function 2-28

Controlling Command Window Input and Output **2-30**
The format Function 2-30
Suppressing Output 2-31
Entering Long Statements 2-32
Command Line Editing 2-32

3 Graphics

Overview of Plotting **3-2**
Plotting Process 3-2
Graph Components 3-6
Figure Tools 3-7
Arranging Graphs Within a Figure 3-14
Choosing a Type of Graph to Plot 3-15

Editing Plots **3-23**
Plot Edit Mode 3-23
Using Functions to Edit Graphs 3-28

Some Ways to Use Plotting Tools **3-29**
Plotting Two Variables with Plotting Tools 3-29
Changing the Appearance of Lines and Markers 3-32
Adding More Data to the Graph 3-33
Changing the Type of Graph 3-36
Modifying the Graph Data Source 3-38

Preparing Graphs for Presentation **3-43**
Annotating Graphs for Presentation **3-43**
Printing the Graph **3-48**
Exporting the Graph **3-52**

Using Basic Plotting Functions **3-56**
Creating a Plot **3-56**
Plotting Multiple Data Sets in One Graph **3-57**
Specifying Line Styles and Colors **3-58**
Plotting Lines and Markers **3-59**
Graphing Imaginary and Complex Data **3-61**
Adding Plots to an Existing Graph **3-62**
Figure Windows **3-63**
Displaying Multiple Plots in One Figure **3-64**
Controlling the Axes **3-66**
Adding Axis Labels and Titles **3-67**
Saving Figures **3-68**

Creating Mesh and Surface Plots **3-72**
About Mesh and Surface Plots **3-72**
Visualizing Functions of Two Variables **3-72**

Plotting Image Data **3-80**
About Plotting Image Data **3-80**
Reading and Writing Images **3-81**

Printing Graphics **3-82**
Overview of Printing **3-82**
Printing from the File Menu **3-82**
Exporting the Figure to a Graphics File **3-83**
Using the Print Command **3-83**

Understanding Handle Graphics Objects **3-85**
Using the Handle **3-85**
Graphics Objects **3-86**
Setting Object Properties **3-88**
Specifying the Axes or Figure **3-91**
Finding the Handles of Existing Objects **3-92**

4 Programming

Flow Control **4-2**
Conditional Control — if, else, switch **4-2**
Loop Control — for, while, continue, break **4-5**
Error Control — try, catch **4-7**
Program Termination — return **4-8**

Other Data Structures **4-9**
Multidimensional Arrays **4-9**
Cell Arrays **4-11**
Characters and Text **4-13**
Structures **4-16**

Scripts and Functions **4-20**
Overview **4-20**
Scripts **4-21**
Functions **4-22**
Types of Functions **4-24**
Global Variables **4-26**
Passing String Arguments to Functions **4-27**
The eval Function **4-28**
Function Handles **4-28**
Function Functions **4-29**
Vectorization **4-31**
Preallocation **4-32**

Object-Oriented Programming **4-33**
MATLAB Classes and Objects **4-33**
Learn About Defining MATLAB Classes **4-33**

5 Data Analysis

Introduction **5-2**

Preprocessing Data **5-3**

Overview 5-3
Loading the Data 5-3
Missing Data 5-3
Outliers 5-4
Smoothing and Filtering 5-6

Summarizing Data **5-10**
Overview 5-10
Measures of Location 5-10
Measures of Scale 5-11
Shape of a Distribution 5-11

Visualizing Data **5-14**
Overview 5-14
2-D Scatter Plots 5-14
3-D Scatter Plots 5-16
Scatter Plot Arrays 5-18
Exploring Data in Graphs 5-19

Modeling Data **5-27**
Overview 5-27
Polynomial Regression 5-27
General Linear Regression 5-28

6 Creating Graphical User Interfaces

What Is GUIDE? **6-2**

Laying Out a GUI **6-3**
Starting GUIDE 6-3
The Layout Editor 6-4

Programming a GUI **6-7**

7 Desktop Tools and Development Environment

Desktop Overview **7-2**
Introduction to the Desktop **7-2**
Arranging the Desktop **7-3**
Start Button **7-3**

Command Window and Command History **7-5**
Command Window **7-5**
Command History **7-6**

Getting Help **7-7**
Ways to Get Help **7-7**
Using the Help Browser to Access Documentation, Examples, and Demos **7-8**

Workspace Browser and Variable Editor **7-19**
Workspace Browser **7-19**
Variable Editor **7-20**

Managing Files in MATLAB **7-21**
How MATLAB Helps You Manage Files **7-21**
Making Files Accessible to MATLAB **7-21**
Using the Current Folder Browser to Manage Files **7-22**
More Ways to Manage Files **7-24**

Finding and Getting Files Created by Other Users — File Exchange **7-25**

Editor **7-27**
Editing M-Files **7-27**
Publishing M-Files **7-29**

Improving and Tuning M-Files **7-33**
Finding Errors Using the M-Lint Code Check Report **7-33**
Improving Performance Using the Profiler **7-35**

8 External Interfaces

Programming Interfaces **8-2**
Call MATLAB Software from C and Fortran Programs ... **8-2**
Call C and Fortran Programs from MATLAB Command Line **8-2**
Call Sun Java Commands from MATLAB Command Line **8-3**
Call Functions in Shared Libraries **8-3**
Import and Export Data **8-3**

Interface to .NET Framework **8-4**

Component Object Model Interface **8-5**

Web Services **8-6**

Serial Port Interface **8-7**

Index

1

Introduction

- “Product Overview” on page 1-2
- “Documentation” on page 1-5
- “Starting and Quitting the MATLAB Program” on page 1-7

Product Overview

In this section...

"Overview of the MATLAB Environment" on page 1-2
"The MATLAB System" on page 1-3

Overview of the MATLAB Environment

The MATLAB® high-performance language for technical computing integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include

- Math and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including graphical user interface building

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. It allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar noninteractive language such as C or Fortran.

The name MATLAB stands for *matrix laboratory*. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation.

MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory

and advanced courses in mathematics, engineering, and science. In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB features a family of add-on application-specific solutions called *toolboxes*. Very important to most users of MATLAB, toolboxes allow you to *learn* and *apply* specialized technology. Toolboxes are comprehensive collections of MATLAB functions that extend the MATLAB environment to solve particular classes of problems. You can add on toolboxes for signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many other areas.

The MATLAB System

The MATLAB system consists of these main parts:

Desktop Tools and Development Environment

This part of MATLAB is the set of tools and facilities that help you use and become more productive with MATLAB functions and files. Many of these tools are graphical user interfaces. It includes: the MATLAB desktop and Command Window, an editor and debugger, a code analyzer, and browsers for viewing help, the workspace, and folders.

Mathematical Function Library

This library is a vast collection of computational algorithms ranging from elementary functions, like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms.

The Language

The MATLAB language is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both “programming in the small” to rapidly create quick programs you do not intend to reuse. You can also do “programming in the large” to create complex application programs intended for reuse.

Graphics

MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications.

External Interfaces

The external interfaces library allows you to write C and Fortran programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), for calling MATLAB as a computational engine, and for reading and writing MAT-files.

Documentation

The MATLAB program provides extensive documentation, in both printable and HTML format, to help you learn about and use all of its features. If you are a new user, begin with this Getting Started guide. It covers all the primary MATLAB features at a high level, including many examples.

To view the online documentation, select **Help > Product Help** in MATLAB. Online help appears in the Help browser, providing task-oriented and reference information about MATLAB features. For more information about using the Help browser, see “Getting Help” on page 7-7.

The MATLAB documentation is organized into these main topics:

- Desktop Tools and Development Environment — Startup and shutdown, arranging the desktop, and using tools to become more productive with MATLAB
- Data Import and Export — Retrieving and storing data, memory-mapping, and accessing Internet files
- Mathematics — Mathematical operations
- Data Analysis — Data analysis, including data fitting, Fourier analysis, and time-series tools
- Programming Fundamentals — The MATLAB language and how to develop MATLAB applications
- Object-Oriented Programming — Designing and implementing MATLAB classes
- Graphics — Tools and techniques for plotting, graph annotation, printing, and programming with Handle Graphics® objects
- 3-D Visualization — Visualizing surface and volume data, transparency, and viewing and lighting techniques
- Creating Graphical User Interfaces — GUI-building tools and how to write callback functions
- External Interfaces — MEX-files, the MATLAB engine, and interfacing to Sun Microsystems™ Java™ software, COM, Web services, and the serial port

There is reference documentation for all MATLAB functions:

- Function Reference — Lists all MATLAB functions, listed in categories or alphabetically
- Handle Graphics Property Browser — Provides easy access to descriptions of graphics object properties
- C and Fortran API Reference — Covers functions used by the MATLAB external interfaces, providing information on syntax in the calling language, description, arguments, return values, and examples

The MATLAB online documentation also includes

- Examples — An index of examples included in the documentation
- Release Notes — New features, compatibility considerations, and bug reports for current and recent previous releases
- Printable Documentation — PDF versions of the documentation, suitable for printing

In addition to the documentation, you can access demos for each product from the Help browser. Run demos to learn about key functionality of MathWorks™ products and tools.

Starting and Quitting the MATLAB Program

In this section…
“Starting a MATLAB Session” on page 1-7 “Quitting the MATLAB Program” on page 1-8

Starting a MATLAB Session

On Microsoft® Windows® platforms, start the MATLAB program by double-clicking the MATLAB shortcut on your Windows desktop.

On Apple® Macintosh® platforms, start MATLAB by double-clicking the MATLAB icon in the `Applications` folder.

On UNIX®[1] platforms, start MATLAB by typing `matlab` at the operating system prompt.

When you start MATLAB, by default, MATLAB automatically loads all the program files provided by The MathWorks for MATLAB and other MathWorks products. You do not have to start each product you want to use.

There are alternative ways to start MATLAB, and you can customize MATLAB startup. For example, you can change the folder in which MATLAB starts or automatically execute MATLAB statements upon startup.

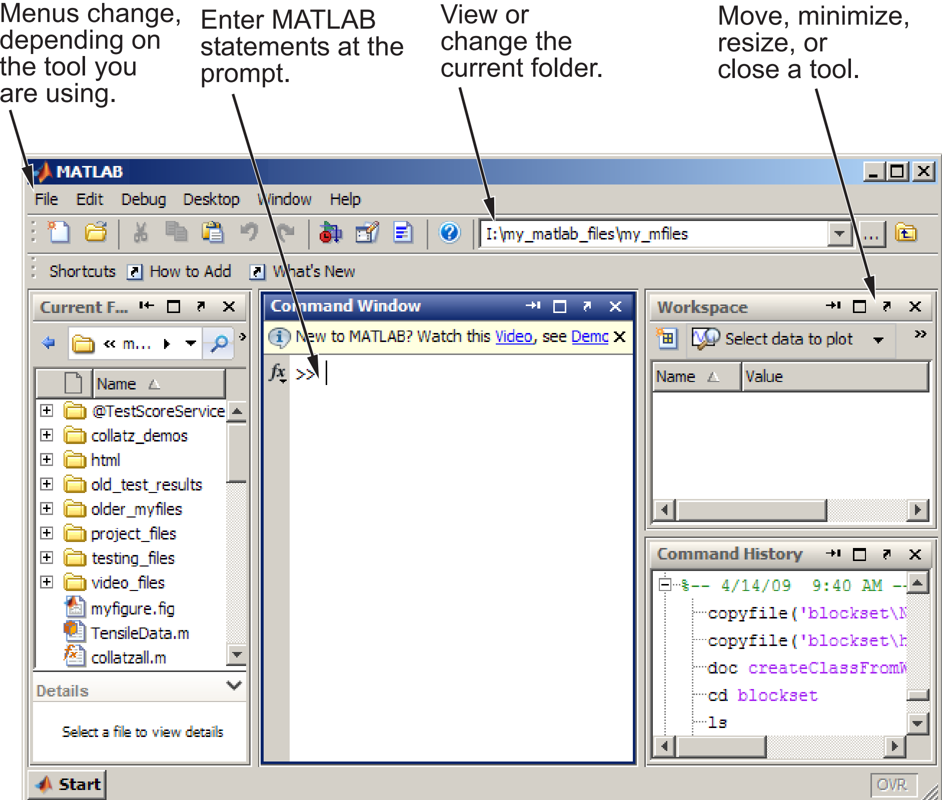
For More Information See “Startup and Shutdown” in the Desktop Tools and Development Environment documentation.

The Desktop

When you start MATLAB, the desktop appears, containing tools (graphical user interfaces) for managing files, variables, and applications associated with MATLAB.

1. UNIX is a registered trademark of The Open Group in the United States and other countries.

The following illustration shows the default desktop. You can customize the arrangement of tools and documents to suit your needs. For more information about the desktop tools, see Chapter 7, “Desktop Tools and Development Environment”.

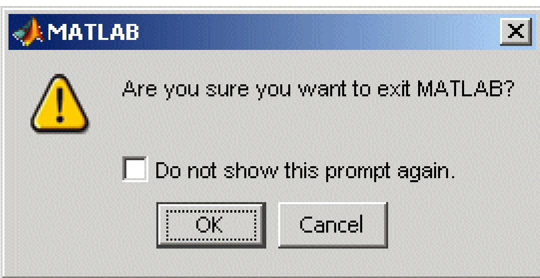


Quitting the MATLAB Program

To end your MATLAB session, select **File > Exit MATLAB** in the desktop, or type `quit` in the Command Window. You can run a script file named `finish.m` each time MATLAB quits that, for example, executes functions to save the workspace.

Confirm Quitting

MATLAB can display a confirmation dialog box before quitting. To set this option, select **File > Preferences > General > Confirmation Dialogs**, and select the check box for **Confirm before exiting MATLAB**.



For More Information See "Quitting the MATLAB Program" in the Desktop Tools and Development Environment documentation.

Matrices and Arrays

You can watch the Getting Started with MATLAB video demo for an overview of the major functionality.

- “Matrices and Magic Squares” on page 2-2
- “Expressions” on page 2-11
- “Working with Matrices” on page 2-16
- “More About Matrices and Arrays” on page 2-20
- “Controlling Command Window Input and Output” on page 2-30

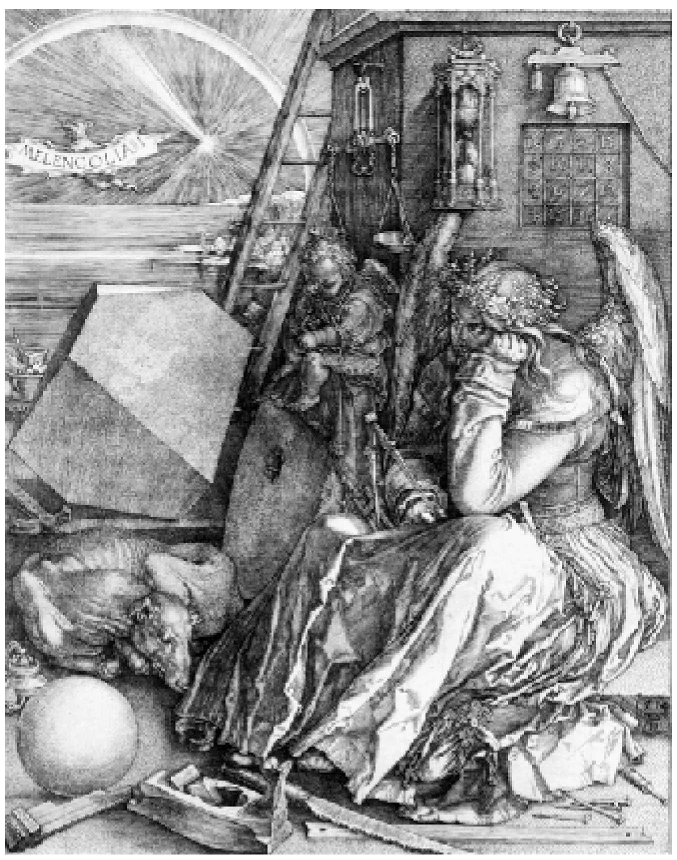
Matrices and Magic Squares

In this section...

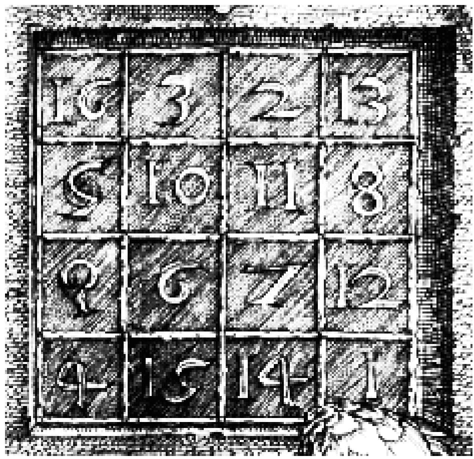
"About Matrices" on page 2-2
"Entering Matrices" on page 2-4
"sum, transpose, and diag" on page 2-5
"Subscripts" on page 2-7
"The Colon Operator" on page 2-8
"The magic Function" on page 2-9

About Matrices

In the MATLAB environment, a matrix is a rectangular array of numbers. Special meaning is sometimes attached to 1-by-1 matrices, which are scalars, and to matrices with only one row or column, which are vectors. MATLAB has other ways of storing both numeric and nonnumeric data, but in the beginning, it is usually best to think of everything as a matrix. The operations in MATLAB are designed to be as natural as possible. Where other programming languages work with numbers one at a time, MATLAB allows you to work with entire matrices quickly and easily. A good example matrix, used throughout this book, appears in the Renaissance engraving Melencolia I by the German artist and amateur mathematician Albrecht Dürer.



This image is filled with mathematical symbolism, and if you look carefully, you will see a matrix in the upper right corner. This matrix is known as a magic square and was believed by many in Dürer's time to have genuinely magical properties. It does turn out to have some fascinating characteristics worth exploring.



Entering Matrices

The best way for you to get started with MATLAB is to learn how to handle matrices. Start MATLAB and follow along with each example.

You can enter matrices into MATLAB in several different ways:

- Enter an explicit list of elements.
- Load matrices from external data files.
- Generate matrices using built-in functions.
- Create matrices with your own functions in M-files.

Start by entering Dürer's matrix as a list of its elements. You only have to follow a few basic conventions:

- Separate the elements of a row with blanks or commas.
- Use a semicolon, `;` , to indicate the end of each row.
- Surround the entire list of elements with square brackets, `[ ]`.

To enter Dürer's matrix, simply type in the Command Window

```
A = [16 3 2 13; 5 10 11 8; 9 6 7 12; 4 15 14 1]
```

MATLAB displays the matrix you just entered:

```
A =
    16     3     2    13
     5    10    11     8
     9     6     7    12
     4    15    14     1
```

This matrix matches the numbers in the engraving. Once you have entered the matrix, it is automatically remembered in the MATLAB workspace. You can refer to it simply as `A`. Now that you have `A` in the workspace, take a look at what makes it so interesting. Why is it magic?

sum, transpose, and diag

You are probably already aware that the special properties of a magic square have to do with the various ways of summing its elements. If you take the sum along any row or column, or along either of the two main diagonals, you will always get the same number. Let us verify that using MATLAB. The first statement to try is

```
sum(A)
```

MATLAB replies with

```
ans =
    34    34    34    34
```

When you do not specify an output variable, MATLAB uses the variable `ans`, short for *answer*, to store the results of a calculation. You have computed a row vector containing the sums of the columns of `A`. Each of the columns has the same sum, the *magic* sum, 34.

How about the row sums? MATLAB has a preference for working with the columns of a matrix, so one way to get the row sums is to transpose the matrix, compute the column sums of the transpose, and then transpose the result. For an additional way that avoids the double transpose use the dimension argument for the `sum` function.

MATLAB has two transpose operators. The apostrophe operator (e.g., `A'`) performs a complex conjugate transposition. It flips a matrix about its main

diagonal, and also changes the sign of the imaginary component of any complex elements of the matrix. The dot-apostrophe operator (e.g., `A.'`), transposes without affecting the sign of complex elements. For matrices containing all real elements, the two operators return the same result.

So

```
A'
```

produces

```
ans =
    16     5     9     4
     3    10     6    15
     2    11     7    14
    13     8    12     1
```

and

```
sum(A')'
```

produces a column vector containing the row sums

```
ans =
    34
    34
    34
    34
```

The sum of the elements on the main diagonal is obtained with the `sum` and the `diag` functions:

```
diag(A)
```

produces

```
ans =
    16
    10
     7
     1
```

and

```
sum(diag(A))
```

produces

```
ans =
    34
```

The other diagonal, the so-called *antidiagonal,* is not so important mathematically, so MATLAB does not have a ready-made function for it. But a function originally intended for use in graphics, `fliplr`, flips a matrix from left to right:

```
sum(diag(fliplr(A)))
ans =
    34
```

You have verified that the matrix in Dürer's engraving is indeed a magic square and, in the process, have sampled a few MATLAB matrix operations. The following sections continue to use this matrix to illustrate additional MATLAB capabilities.

Subscripts

The element in row `i` and column `j` of `A` is denoted by `A(i,j)`. For example, `A(4,2)` is the number in the fourth row and second column. For the magic square, `A(4,2)` is `15`. So to compute the sum of the elements in the fourth column of `A`, type

```
A(1,4) + A(2,4) + A(3,4) + A(4,4)
```

This subscript produces

```
ans =
     34
```

but is not the most elegant way of summing a single column.

It is also possible to refer to the elements of a matrix with a single subscript, `A(k)`. A single subscript is the usual way of referencing row and column vectors. However, it can also apply to a fully two-dimensional matrix, in

which case the array is regarded as one long column vector formed from the columns of the original matrix. So, for the magic square, `A(8)` is another way of referring to the value `15` stored in `A(4,2)`.

If you try to use the value of an element outside of the matrix, it is an error:

```
t = A(4,5)
Index exceeds matrix dimensions.
```

Conversely, if you store a value in an element outside of the matrix, the size increases to accommodate the newcomer:

```
X = A;
X(4,5) = 17

X =
    16     3     2    13     0
     5    10    11     8     0
     9     6     7    12     0
     4    15    14     1    17
```

The Colon Operator

The colon, `:`, is one of the most important MATLAB operators. It occurs in several different forms. The expression

```
1:10
```

is a row vector containing the integers from 1 to 10:

```
1     2     3     4     5     6     7     8     9    10
```

To obtain nonunit spacing, specify an increment. For example,

```
100:-7:50
```

is

```
100    93    86    79    72    65    58    51
```

and

```
0:pi/4:pi
```

is

```
0    0.7854    1.5708    2.3562    3.1416
```

Subscript expressions involving colons refer to portions of a matrix:

```
A(1:k,j)
```

is the first `k` elements of the `j`th column of `A`. Thus:

```
sum(A(1:4,4))
```

computes the sum of the fourth column. However, there is a better way to perform this computation. The colon by itself refers to *all* the elements in a row or column of a matrix and the keyword `end` refers to the *last* row or column. Thus:

```
sum(A(:,end))
```

computes the sum of the elements in the last column of `A`:

```
ans =
     34
```

Why is the magic sum for a 4-by-4 square equal to 34? If the integers from 1 to 16 are sorted into four groups with equal sums, that sum must be

```
sum(1:16)/4
```

which, of course, is

```
ans =
     34
```

The magic Function

MATLAB actually has a built-in function that creates magic squares of almost any size. Not surprisingly, this function is named `magic`:

```
B = magic(4)
B =
    16     2     3    13
     5    11    10     8
     9     7     6    12
     4    14    15     1
```

This matrix is almost the same as the one in the Dürer engraving and has all the same “magic” properties; the only difference is that the two middle columns are exchanged.

To make this `B` into Dürer’s `A`, swap the two middle columns:

```
A = B(:,[1 3 2 4])
```

This subscript indicates that—for each of the rows of matrix `B`—reorder the elements in the order 1, 3, 2, 4. It produces:

```
A =
    16     3     2    13
     5    10    11     8
     9     6     7    12
     4    15    14     1
```

Expressions

In this section...

"Variables" on page 2-11
"Numbers" on page 2-12
"Operators" on page 2-13
"Functions" on page 2-13
"Examples of Expressions" on page 2-15

Variables

Like most other programming languages, the MATLAB language provides mathematical *expressions*, but unlike most programming languages, these expressions involve entire matrices.

MATLAB does not require any type declarations or dimension statements. When MATLAB encounters a new variable name, it automatically creates the variable and allocates the appropriate amount of storage. If the variable already exists, MATLAB changes its contents and, if necessary, allocates new storage. For example,

```
num_students = 25
```

creates a 1-by-1 matrix named `num_students` and stores the value 25 in its single element. To view the matrix assigned to any variable, simply enter the variable name.

Variable names consist of a letter, followed by any number of letters, digits, or underscores. MATLAB is case sensitive; it distinguishes between uppercase and lowercase letters. `A` and `a` are *not* the same variable.

Although variable names can be of any length, MATLAB uses only the first `N` characters of the name, (where `N` is the number returned by the function `namelengthmax`), and ignores the rest. Hence, it is important to make each variable name unique in the first `N` characters to enable MATLAB to distinguish variables.

```
N = namelengthmax
N =
    63
```

The `genvarname` function can be useful in creating variable names that are both valid and unique.

Numbers

MATLAB uses conventional decimal notation, with an optional decimal point and leading plus or minus sign, for numbers. Scientific notation uses the letter `e` to specify a power-of-ten scale factor. Imaginary numbers use either `i` or `j` as a suffix. Some examples of legal numbers are

```
3              -99            0.0001
9.6397238      1.60210e-20    6.02252e23
1i             -3.14159j      3e5i
```

All numbers are stored internally using the *long* format specified by the IEEE® floating-point standard. Floating-point numbers have a finite *precision* of roughly 16 significant decimal digits and a finite *range* of roughly 10^{-308} to 10^{+308}.

The section “Avoiding Common Problems with Floating-Point Arithmetic” gives a few of the examples showing how IEEE floating-point arithmetic affects computations in MATLAB. For more examples and information, see Technical Note 1108 — Common Problems with Floating-Point Arithmetic.

MATLAB software stores the real and imaginary parts of a complex number. It handles the magnitude of the parts in different ways depending on the context. For instance, the `sort` function sorts based on magnitude and resolves ties by phase angle.

```
sort([3+4i, 4+3i])
ans =
   4.0000 + 3.0000i   3.0000 + 4.0000i
```

This is because of the phase angle:

```
angle(3+4i)
ans =
```

```
    0.9273
angle(4+3i)
ans =
    0.6435
```

The “equal to” relational operator == requires both the real and imaginary parts to be equal. The other binary relational operators > <, >=, and <= ignore the imaginary part of the number and consider the real part only.

Operators

Expressions use familiar arithmetic operators and precedence rules.

+	Addition
-	Subtraction
*	Multiplication
/	Division
\	Left division (described in “Linear Algebra” in the MATLAB documentation)
^	Power
'	Complex conjugate transpose
( )	Specify evaluation order

Functions

MATLAB provides a large number of standard elementary mathematical functions, including `abs`, `sqrt`, `exp`, and `sin`. Taking the square root or logarithm of a negative number is not an error; the appropriate complex result is produced automatically. MATLAB also provides many more advanced mathematical functions, including Bessel and gamma functions. Most of these functions accept complex arguments. For a list of the elementary mathematical functions, type

```
help elfun
```

For a list of more advanced mathematical and matrix functions, type

```
help specfun
help elmat
```

Some of the functions, like `sqrt` and `sin`, are *built in*. Built-in functions are part of the MATLAB core so they are very efficient, but the computational details are not readily accessible. Other functions, like `gamma` and `sinh`, are implemented in M-files.

There are some differences between built-in functions and other functions. For example, for built-in functions, you cannot see the code. For other functions, you can see the code and even modify it if you want.

Several special functions provide values of useful constants.

`pi`	3.14159265...
`i`	Imaginary unit, $\sqrt{-1}$
`j`	Same as `i`
`eps`	Floating-point relative precision, $\varepsilon = 2^{-52}$
`realmin`	Smallest floating-point number, 2^{-1022}
`realmax`	Largest floating-point number, $(2-\varepsilon)2^{1023}$
`Inf`	Infinity
`NaN`	Not-a-number

Infinity is generated by dividing a nonzero value by zero, or by evaluating well defined mathematical expressions that *overflow*, i.e., exceed `realmax`. Not-a-number is generated by trying to evaluate expressions like `0/0` or `Inf-Inf` that do not have well defined mathematical values.

The function names are not reserved. It is possible to overwrite any of them with a new variable, such as

```
eps = 1.e-6
```

and then use that value in subsequent calculations. The original function can be restored with

```
clear eps
```

Examples of Expressions

You have already seen several examples of MATLAB expressions. Here are a few more examples, and the resulting values:

```
rho = (1+sqrt(5))/2
rho =
    1.6180

a = abs(3+4i)
a =
     5

z = sqrt(besselk(4/3,rho-i))
z =
   0.3730+ 0.3214i

huge = exp(log(realmax))
huge =
  1.7977e+308

toobig = pi*huge
toobig =
   Inf
```

Working with Matrices

In this section...
"Generating Matrices" on page 2-16
"The load Function" on page 2-17
"M-Files" on page 2-17
"Concatenation" on page 2-18
"Deleting Rows and Columns" on page 2-19

Generating Matrices

MATLAB software provides four functions that generate basic matrices.

`zeros`	All zeros
`ones`	All ones
`rand`	Uniformly distributed random elements
`randn`	Normally distributed random elements

Here are some examples:

```
Z = zeros(2,4)
Z =
     0     0     0     0
     0     0     0     0

F = 5*ones(3,3)
F =
     5     5     5
     5     5     5
     5     5     5

N = fix(10*rand(1,10))
N =
     9     2     6     4     8     7     4     0     8     4
```

```
R = randn(4,4)
R =
    0.6353    0.0860   -0.3210   -1.2316
   -0.6014   -2.0046    1.2366    1.0556
    0.5512   -0.4931   -0.6313   -0.1132
   -1.0998    0.4620   -2.3252    0.3792
```

The load Function

The `load` function reads binary files containing matrices generated by earlier MATLAB sessions, or reads text files containing numeric data. The text file should be organized as a rectangular table of numbers, separated by blanks, with one row per line, and an equal number of elements in each row. For example, outside of MATLAB, create a text file containing these four lines:

```
16.0     3.0     2.0    13.0
 5.0    10.0    11.0     8.0
 9.0     6.0     7.0    12.0
 4.0    15.0    14.0     1.0
```

Save the file as `magik.dat` in the current directory. The statement

```
load magik.dat
```

reads the file and creates a variable, `magik`, containing the example matrix.

An easy way to read data into MATLAB from many text or binary formats is to use the Import Wizard.

M-Files

You can create your own matrices using *M-files*, which are text files containing MATLAB code. Use the MATLAB Editor or another text editor to create a file containing the same statements you would type at the MATLAB command line. Save the file under a name that ends in `.m`.

For example, create a file in the current directory named `magik.m` containing these five lines:

```
A = [16.0     3.0     2.0    13.0
      5.0    10.0    11.0     8.0
      9.0     6.0     7.0    12.0
      4.0    15.0    14.0     1.0 ];
```

The statement

```
magik
```

reads the file and creates a variable, A, containing the example matrix.

Concatenation

Concatenation is the process of joining small matrices to make bigger ones. In fact, you made your first matrix by concatenating its individual elements. The pair of square brackets, [], is the concatenation operator. For an example, start with the 4-by-4 magic square, A, and form

```
B = [A  A+32; A+48  A+16]
```

The result is an 8-by-8 matrix, obtained by joining the four submatrices:

```
B =

    16     3     2    13    48    35    34    45
     5    10    11     8    37    42    43    40
     9     6     7    12    41    38    39    44
     4    15    14     1    36    47    46    33
    64    51    50    61    32    19    18    29
    53    58    59    56    21    26    27    24
    57    54    55    60    25    22    23    28
    52    63    62    49    20    31    30    17
```

This matrix is halfway to being another magic square. Its elements are a rearrangement of the integers 1:64. Its column sums are the correct value for an 8-by-8 magic square:

```
sum(B)

ans =
   260   260   260   260   260   260   260   260
```

But its row sums, `sum(B')'`, are not all the same. Further manipulation is necessary to make this a valid 8-by-8 magic square.

Deleting Rows and Columns

You can delete rows and columns from a matrix using just a pair of square brackets. Start with

```
X = A;
```

Then, to delete the second column of `X`, use

```
X(:,2) = []
```

This changes `X` to

```
X =
    16     2    13
     5    11     8
     9     7    12
     4    14     1
```

If you delete a single element from a matrix, the result is not a matrix anymore. So, expressions like

```
X(1,2) = []
```

result in an error. However, using a single subscript deletes a single element, or sequence of elements, and reshapes the remaining elements into a row vector. So

```
X(2:2:10) = []
```

results in

```
X =
    16     9     2     7    13    12     1
```

More About Matrices and Arrays

In this section...

"Linear Algebra" on page 2-20

"Arrays" on page 2-24

"Multivariate Data" on page 2-26

"Scalar Expansion" on page 2-27

"Logical Subscripting" on page 2-27

"The find Function" on page 2-28

Linear Algebra

Informally, the terms *matrix* and *array* are often used interchangeably. More precisely, a *matrix* is a two-dimensional numeric array that represents a linear transformation. The mathematical operations defined on matrices are the subject of linear algebra.

Dürer's magic square

```
A = [16     3     2    13
      5    10    11     8
      9     6     7    12
      4    15    14     1 ]
```

provides several examples that give a taste of MATLAB matrix operations. You have already seen the matrix transpose, `A'`. Adding a matrix to its transpose produces a *symmetric* matrix:

```
A + A'

ans =
    32     8    11    17
     8    20    17    23
    11    17    14    26
    17    23    26     2
```

The multiplication symbol, `*`, denotes the *matrix* multiplication involving inner products between rows and columns. Multiplying the transpose of a matrix by the original matrix also produces a symmetric matrix:

```
A'*A

ans =
   378   212   206   360
   212   370   368   206
   206   368   370   212
   360   206   212   378
```

The determinant of this particular matrix happens to be zero, indicating that the matrix is *singular*:

```
d = det(A)

d =
     0
```

The reduced row echelon form of `A` is not the identity:

```
R = rref(A)

R =
     1     0     0     1
     0     1     0    -3
     0     0     1     3
     0     0     0     0
```

Because the matrix is singular, it does not have an inverse. If you try to compute the inverse with

```
X = inv(A)
```

you will get a warning message:

```
Warning: Matrix is close to singular or badly scaled.
         Results may be inaccurate. RCOND = 9.796086e-018.
```

Roundoff error has prevented the matrix inversion algorithm from detecting exact singularity. But the value of `rcond`, which stands for *reciprocal*

condition estimate, is on the order of eps, the floating-point relative precision, so the computed inverse is unlikely to be of much use.

The eigenvalues of the magic square are interesting:

```
e = eig(A)

e =
   34.0000
    8.0000
    0.0000
   -8.0000
```

One of the eigenvalues is zero, which is another consequence of singularity. The largest eigenvalue is 34, the magic sum. That sum results because the vector of all ones is an eigenvector:

```
v = ones(4,1)

v =
     1
     1
     1
     1

A*v

ans =
    34
    34
    34
    34
```

When a magic square is scaled by its magic sum,

```
P = A/34
```

the result is a *doubly stochastic* matrix whose row and column sums are all 1:

```
P =
    0.4706    0.0882    0.0588    0.3824
    0.1471    0.2941    0.3235    0.2353
    0.2647    0.1765    0.2059    0.3529
    0.1176    0.4412    0.4118    0.0294
```

Such matrices represent the transition probabilities in a *Markov process*. Repeated powers of the matrix represent repeated steps of the process. For this example, the fifth power

```
P^5
```

is

```
    0.2507    0.2495    0.2494    0.2504
    0.2497    0.2501    0.2502    0.2500
    0.2500    0.2498    0.2499    0.2503
    0.2496    0.2506    0.2505    0.2493
```

This shows that as k approaches infinity, all the elements in the kth power, p^k, approach $1/4$.

Finally, the coefficients in the characteristic polynomial

```
poly(A)
```

are

```
     1   -34   -64  2176     0
```

These coefficients indicate that the characteristic polynomial

$$\det(A - \lambda I)$$

is

$$\lambda^4 - 34\lambda^3 - 64\lambda^2 + 2176\lambda$$

The constant term is zero because the matrix is singular. The coefficient of the cubic term is -34 because the matrix is magic!

Arrays

When they are taken away from the world of linear algebra, matrices become two-dimensional numeric arrays. Arithmetic operations on arrays are done element by element. This means that addition and subtraction are the same for arrays and matrices, but that multiplicative operations are different. MATLAB uses a dot, or decimal point, as part of the notation for multiplicative array operations.

The list of operators includes

`+`	Addition
`-`	Subtraction
`.*`	Element-by-element multiplication
`./`	Element-by-element division
`.\`	Element-by-element left division
`.^`	Element-by-element power
`.'`	Unconjugated array transpose

If the Dürer magic square is multiplied by itself with array multiplication

```
A.*A
```

the result is an array containing the squares of the integers from 1 to 16, in an unusual order:

```
ans =
   256     9     4   169
    25   100   121    64
    81    36    49   144
    16   225   196     1
```

Building Tables

Array operations are useful for building tables. Suppose n is the column vector

```
n = (0:9)';
```

Then

```
pows = [n  n.^2  2.^n]
```

builds a table of squares and powers of 2:

```
pows =
     0     0     1
     1     1     2
     2     4     4
     3     9     8
     4    16    16
     5    25    32
     6    36    64
     7    49   128
     8    64   256
     9    81   512
```

The elementary math functions operate on arrays element by element. So

```
format short g
x = (1:0.1:2)';
logs = [x log10(x)]
```

builds a table of logarithms.

```
 logs =
      1.0            0
      1.1      0.04139
      1.2      0.07918
      1.3      0.11394
      1.4      0.14613
      1.5      0.17609
      1.6      0.20412
      1.7      0.23045
      1.8      0.25527
      1.9      0.27875
      2.0      0.30103
```

Multivariate Data

MATLAB uses column-oriented analysis for multivariate statistical data. Each column in a data set represents a variable and each row an observation. The `(i,j)`th element is the `i`th observation of the `j`th variable.

As an example, consider a data set with three variables:

- Heart rate
- Weight
- Hours of exercise per week

For five observations, the resulting array might look like

```
D = [ 72          134          3.2
      81          201          3.5
      69          156          7.1
      82          148          2.4
      75          170          1.2 ]
```

The first row contains the heart rate, weight, and exercise hours for patient 1, the second row contains the data for patient 2, and so on. Now you can apply many MATLAB data analysis functions to this data set. For example, to obtain the mean and standard deviation of each column, use

```
mu = mean(D), sigma = std(D)

mu =
      75.8       161.8         3.48

sigma =
    5.6303      25.499       2.2107
```

For a list of the data analysis functions available in MATLAB, type

```
help datafun
```

If you have access to the Statistics Toolbox™ software, type

```
help stats
```

Scalar Expansion

Matrices and scalars can be combined in several different ways. For example, a scalar is subtracted from a matrix by subtracting it from each element. The average value of the elements in our magic square is 8.5, so

```
B = A - 8.5
```

forms a matrix whose column sums are zero:

```
B =
     7.5     -5.5     -6.5      4.5
    -3.5      1.5      2.5     -0.5
     0.5     -2.5     -1.5      3.5
    -4.5      6.5      5.5     -7.5

sum(B)

ans =
     0     0     0     0
```

With scalar expansion, MATLAB assigns a specified scalar to all indices in a range. For example,

```
B(1:2,2:3) = 0
```

zeroes out a portion of `B`:

```
B =
     7.5        0        0      4.5
    -3.5        0        0     -0.5
     0.5     -2.5     -1.5      3.5
    -4.5      6.5      5.5     -7.5
```

Logical Subscripting

The logical vectors created from logical and relational operations can be used to reference subarrays. Suppose `X` is an ordinary matrix and `L` is a matrix of the same size that is the result of some logical operation. Then `X(L)` specifies the elements of `X` where the elements of `L` are nonzero.

This kind of subscripting can be done in one step by specifying the logical operation as the subscripting expression. Suppose you have the following set of data:

```
x = [2.1 1.7 1.6 1.5 NaN 1.9 1.8 1.5 5.1 1.8 1.4 2.2 1.6 1.8];
```

The `NaN` is a marker for a missing observation, such as a failure to respond to an item on a questionnaire. To remove the missing data with logical indexing, use `isfinite(x)`, which is true for all finite numerical values and false for `NaN` and `Inf`:

```
x = x(isfinite(x))
x =
  2.1 1.7 1.6 1.5 1.9 1.8 1.5 5.1 1.8 1.4 2.2 1.6 1.8
```

Now there is one observation, `5.1`, which seems to be very different from the others. It is an *outlier*. The following statement removes outliers, in this case those elements more than three standard deviations from the mean:

```
x = x(abs(x-mean(x)) <= 3*std(x))
x =
  2.1 1.7 1.6 1.5 1.9 1.8 1.5 1.8 1.4 2.2 1.6 1.8
```

For another example, highlight the location of the prime numbers in Dürer's magic square by using logical indexing and scalar expansion to set the nonprimes to 0. (See "The magic Function" on page 2-9.)

```
A(~isprime(A)) = 0

A =
     0     3     2    13
     5     0    11     0
     0     0     7     0
     0     0     0     0
```

The find Function

The `find` function determines the indices of array elements that meet a given logical condition. In its simplest form, `find` returns a column vector of indices. Transpose that vector to obtain a row vector of indices. For example, start again with Dürer's magic square. (See "The magic Function" on page 2-9.)

```
k = find(isprime(A))'
```

picks out the locations, using one-dimensional indexing, of the primes in the magic square:

```
k =
     2     5     9    10    11    13
```

Display those primes, as a row vector in the order determined by `k`, with

```
A(k)

ans =
     5     3     2    11     7    13
```

When you use `k` as a left-hand-side index in an assignment statement, the matrix structure is preserved:

```
A(k) = NaN

A =
    16   NaN   NaN   NaN
   NaN    10   NaN     8
     9     6   NaN    12
     4    15    14     1
```

Controlling Command Window Input and Output

In this section...

"The format Function" on page 2-30
"Suppressing Output" on page 2-31
"Entering Long Statements" on page 2-32
"Command Line Editing" on page 2-32

The format Function

The `format` function controls the numeric format of the values displayed. The function affects only how numbers are displayed, not how MATLAB software computes or saves them. Here are the different formats, together with the resulting output produced from a vector `x` with components of different magnitudes.

Note To ensure proper spacing, use a fixed-width font, such as Courier.

```
x = [4/3 1.2345e-6]

format short

   1.3333    0.0000

format short e

   1.3333e+000  1.2345e-006

format short g

   1.3333  1.2345e-006

format long

   1.33333333333333   0.00000123450000
```

```
format long e

   1.333333333333333e+000    1.234500000000000e-006

format long g

   1.33333333333333              1.2345e-006

format bank

   1.33          0.00

format rat

   4/3          1/810045

format hex

   3ff5555555555555   3eb4b6231abfd271
```

If the largest element of a matrix is larger than 10^3 or smaller than 10^{-3}, MATLAB applies a common scale factor for the short and long formats.

In addition to the `format` functions shown above

```
format compact
```

suppresses many of the blank lines that appear in the output. This lets you view more information on a screen or window. If you want more control over the output format, use the `sprintf` and `fprintf` functions.

Suppressing Output

If you simply type a statement and press **Return** or **Enter**, MATLAB automatically displays the results on screen. However, if you end the line with a semicolon, MATLAB performs the computation but does not display any output. This is particularly useful when you generate large matrices. For example,

```
A = magic(100);
```

Entering Long Statements

If a statement does not fit on one line, use an ellipsis (three periods), `...`, followed by **Return** or **Enter** to indicate that the statement continues on the next line. For example,

```
s = 1 -1/2 + 1/3 -1/4 + 1/5 - 1/6 + 1/7 ...
      - 1/8 + 1/9 - 1/10 + 1/11 - 1/12;
```

Blank spaces around the =, +, and - signs are optional, but they improve readability.

Command Line Editing

Various arrow and control keys on your keyboard allow you to recall, edit, and reuse statements you have typed earlier. For example, suppose you mistakenly enter

```
rho = (1 + sqt(5))/2
```

You have misspelled `sqrt`. MATLAB responds with

```
Undefined function or variable 'sqt'.
```

Instead of retyping the entire line, simply press the ↑ key. The statement you typed is redisplayed. Use the ← key to move the cursor over and insert the missing `r`. Repeated use of the ↑ key recalls earlier lines. Typing a few characters and then the ↑ key finds a previous line that begins with those characters. You can also copy previously executed statements from the Command History. For more information, see "Command History" on page 7-6.

Graphics

- "Overview of Plotting" on page 3-2
- "Editing Plots" on page 3-23
- "Some Ways to Use Plotting Tools" on page 3-29
- "Preparing Graphs for Presentation" on page 3-43
- "Using Basic Plotting Functions" on page 3-56
- "Creating Mesh and Surface Plots" on page 3-72
- "Plotting Image Data" on page 3-80
- "Printing Graphics" on page 3-82
- "Understanding Handle Graphics Objects" on page 3-85

Overview of Plotting

In this section...

"Plotting Process" on page 3-2

"Graph Components" on page 3-6

"Figure Tools" on page 3-7

"Arranging Graphs Within a Figure" on page 3-14

"Choosing a Type of Graph to Plot" on page 3-15

For More Information See MATLAB Graphics and 3-D Visualization in the MATLAB documentation for in-depth coverage of MATLAB graphics and visualization tools. Access these topics from the Help browser.

Plotting Process

The MATLAB environment provides a wide variety of techniques to display data graphically. Interactive tools enable you to manipulate graphs to achieve results that reveal the most information about your data. You can also annotate and print graphs for presentations, or export graphs to standard graphics formats for presentation in Web browsers or other media.

The process of visualizing data typically involves a series of operations. This section provides a "big picture" view of the plotting process and contains links to sections that have examples and specific details about performing each operation.

Creating a Graph

The type of graph you choose to create depends on the nature of your data and what you want to reveal about the data. You can choose from many predefined graph types, such as line, bar, histogram, and pie graphs as well as 3-D graphs, such as surfaces, slice planes, and streamlines.

There are two basic ways to create MATLAB graphs:

- Use plotting tools to create graphs interactively.

See “Some Ways to Use Plotting Tools” on page 3-29.

- Use the command interface to enter commands in the Command Window or create plotting programs.

  See “Using Basic Plotting Functions” on page 3-56.

You might find it useful to combine both approaches. For example, you might issue a plotting command to create a graph and then modify the graph using one of the interactive tools.

Exploring Data

After you create a graph, you can extract specific information about the data, such as the numeric value of a peak in a plot, the average value of a series of data, or you can perform data fitting. You can also identify individual graph observations with Datatip and Data brushing tools and trace them back to their data sources in the MATLAB workspace.

For More Information See “Data Exploration Tools” in the MATLAB Graphics documentation and “Marking Up Graphs with Data Brushing”, “Making Graphs Responsive with Data Linking”, “Interacting with Graphed Data”, and “Opening the Basic Fitting GUI” in the MATLAB Data Analysis documentation.

Editing the Graph Components

Graphs are composed of objects, which have properties you can change. These properties affect the way the various graph components look and behave.

For example, the axes used to define the coordinate system of the graph has properties that define the limits of each axis, the scale, color, etc. The line used to create a line graph has properties such as color, type of marker used at each data point (if any), line style, etc.

Note The data values that a line graph (for example) displays are copied into and become properties of the (lineseries) graphics object. You can, therefore, change the data in the workspace without creating a new graph. You can also add data to a graph. See "Editing Plots" on page 3-23 for more information.

Annotating Graphs

Annotations are the text, arrows, callouts, and other labels added to graphs to help viewers see what is important about the data. You typically add annotations to graphs when you want to show them to other people or when you want to save them for later reference.

For More Information See "Annotating Graphs" in the MATLAB Graphics documentation, or select **Annotating Graphs** from the figure **Help** menu.

Printing and Exporting Graphs

You can print your graph on any printer connected to your computer. The print previewer enables you to view how your graph will look when printed. It enables you to add headers, footers, a date, and so on. The print preview dialog box lets you control the size, layout, and other characteristics of the graph (select **Print Preview** from the figure **File** menu).

Exporting a graph means creating a copy of it in a standard graphics file format, such as TIFF, JPEG, or EPS. You can then import the file into a word processor, include it in an HTML document, or edit it in a drawing package (select **Export Setup** from the figure **File** menu).

Adding and Removing Figure Content

By default, when you create a new graph in the same figure window, its data replaces that of the graph that is currently displayed, if any. You can add new data to a graph in several ways; see "Adding More Data to the Graph" on page 3-33 for how to do this using a GUI. You can manually remove all data, graphics and annotations from the current figure by typing `clf` in the Command Window or by selecting **Clear Figure** from the figure's **Edit** menu.

For More Information See the `print` command reference page and “Printing and Exporting” in the MATLAB Graphics documentation, or select **Printing and Exporting** from the figure **Help** menu.

Saving Graphs for Reuse

There are two ways to save graphs that enable you to save the work you have invested in their preparation:

- Save the graph as a FIG-file (select **Save** from the figure **File** menu).
- Generate MATLAB code that can recreate the graph (select **Generate M-File** from the figure **File** menu).

FIG-Files. FIG-files are a binary format that saves a figure in its current state. This means that all graphics objects and property settings are stored in the file when you create it. You can reload the file into a different MATLAB session, even when you run it on a different type of computer. When you load a FIG-file, a new MATLAB figure opens in the same state as the one you saved.

Note The states of any figure tools on the toolbars are not saved in a FIG-file; only the contents of the graph and its annotations are saved. The contents of datatips (created by the Data Cursor tool), are also saved. This means that FIG-files always open in the default figure mode.

Generated Code. You can use the MATLAB M-code generator to create code that recreates the graph. Unlike a FIG-file, the generated code does not contain any data. You must pass appropriate data to the generated function when you run the code.

Studying the generated code for a graph is a good way to learn how to program using MATLAB.

For More Information See the `print` command reference page and “Saving Your Work” in the MATLAB Graphics documentation.

Graph Components

MATLAB graphs display in a special window known as a *figure*. To create a graph, you need to define a coordinate system. Therefore, every graph is placed within axes, which are contained by the figure.

You achieve the actual visual representation of the data with graphics objects like lines and surfaces. These objects are drawn within the coordinate system defined by the axes, which appear automatically to specifically span the range of the data. The actual data is stored as properties of the graphics objects.

See "Understanding Handle Graphics Objects" on page 3-85 for more information about graphics object properties.

The following picture shows the basic components of a typical graph. You can find commands for plotting this graph in "Preparing Graphs for Presentation" on page 3-43.

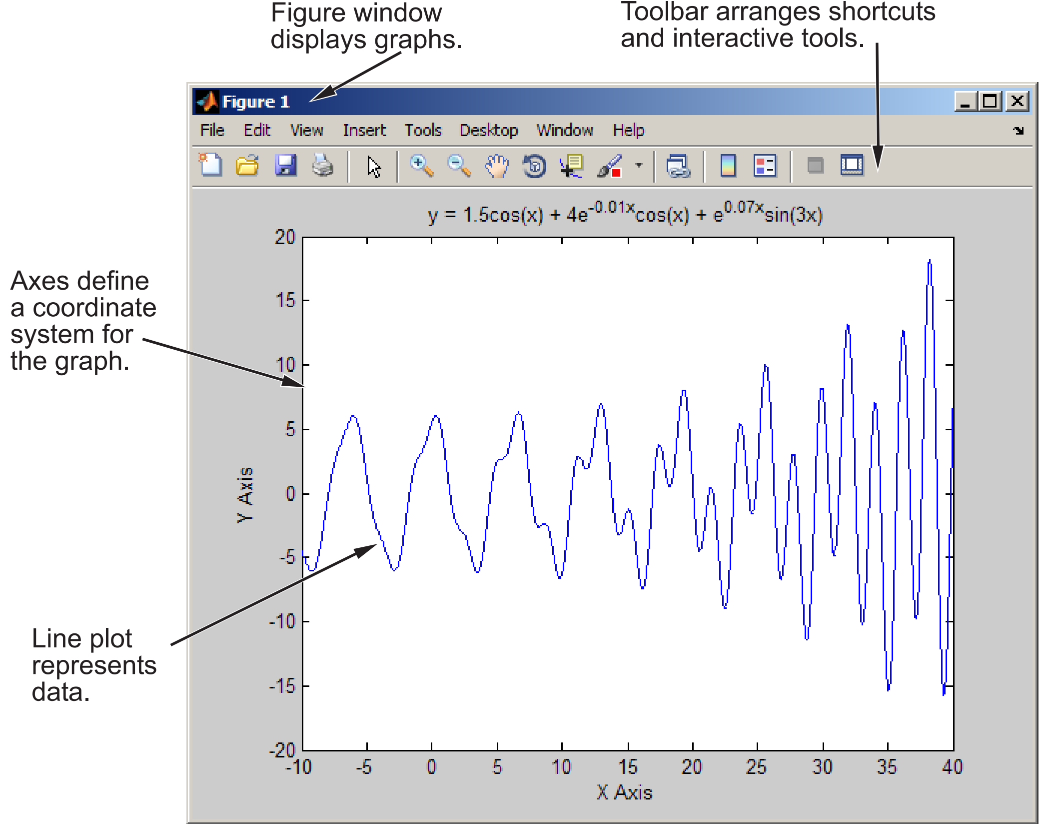
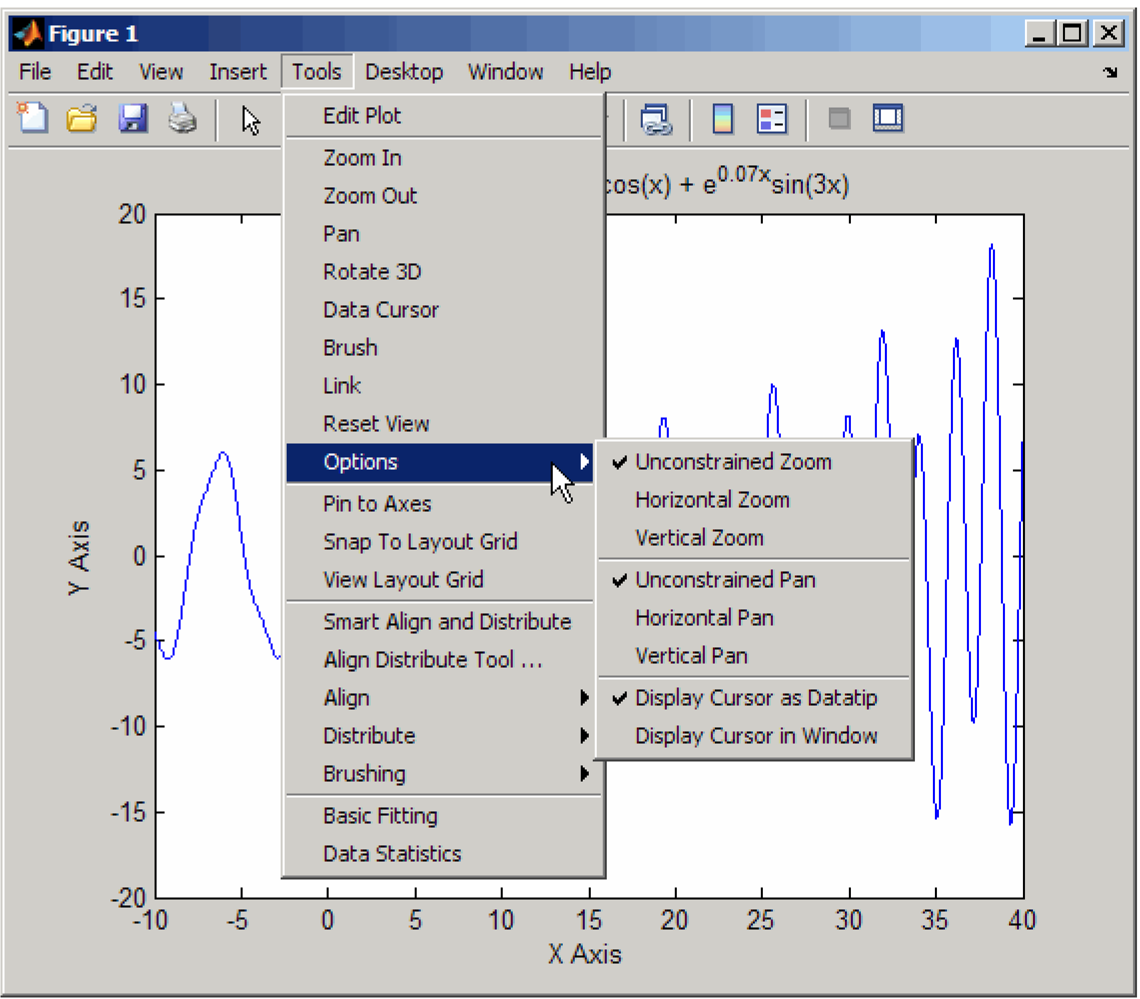


Figure Tools

The figure is equipped with sets of tools that operate on graphs. The figure **Tools** menu provides access to many graph tools, as this view of the **Options** submenu illustrates. Many of the options shown in this figure also appear as context menu items for individual tools such as zoom and pan. The figure also shows three figure toolbars, discussed in “Figure Toolbars” on page 3-9.



For More Information See "Plots and Plotting Tools" in the MATLAB Graphics documentation, or select **Plotting Tools** from the figure **Help** menu.

Accessing the Tools

You can access or remove the figure toolbars and the plotting tools from the **View** menu, as shown in the following picture. Toggle on and off the toolbars you need. Adding a toolbar stacks it beneath the lowest one.

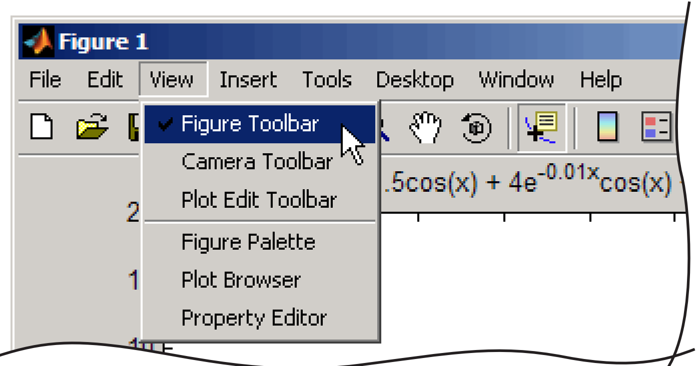
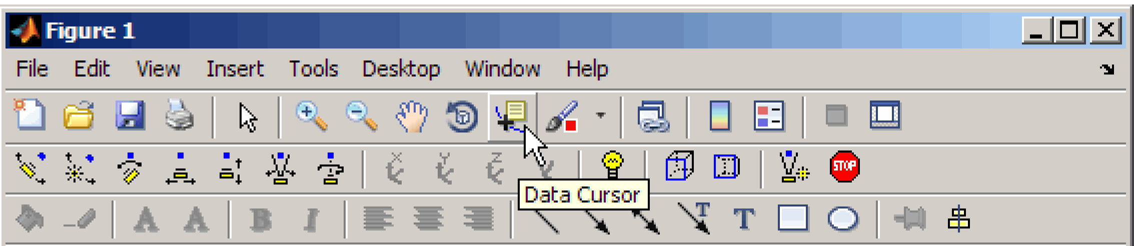


Figure Toolbars

Figure toolbars provide easy access to many graph modification features. There are three toolbars. When you place the cursor over a particular tool, a text box pops up with the tool name. The following picture shows the three toolbars displayed with the cursor over the **Data Cursor** tool.



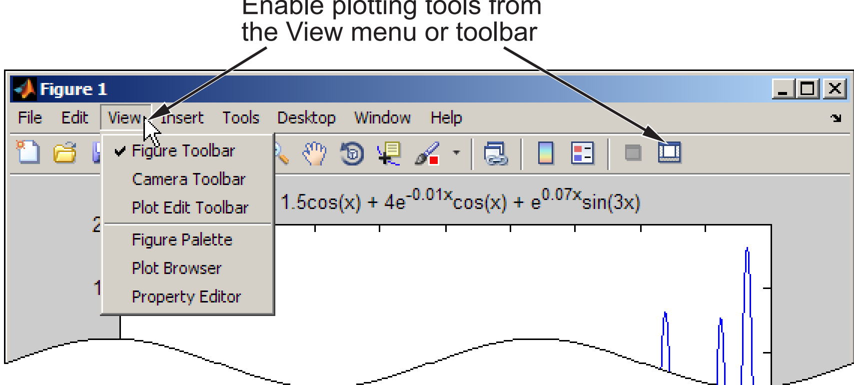
For More Information See "Anatomy of a Graph" in the MATLAB Graphics documentation.

Plotting Tools

Plotting tools are attached to figures and create an environment for creating graphs. These tools enable you to perform the following tasks:

- Select from a wide variety of graph types.
- Change the type of graph that represents a variable.
- See and set the properties of graphics objects.
- Annotate graphs with text, arrows, etc.
- Create and arrange subplots in the figure.
- Drag and drop data into graphs.

Display the plotting tools from the **View** menu or by clicking the **Show Plot Tools** icon in the figure toolbar, as shown in the following picture.



You can also start the plotting tools from the MATLAB prompt:

```
plottools
```

The plotting tools are made up of three independent GUI components:

- Figure Palette — Specify and arrange subplots, access workspace variables for plotting or editing, and add annotations.

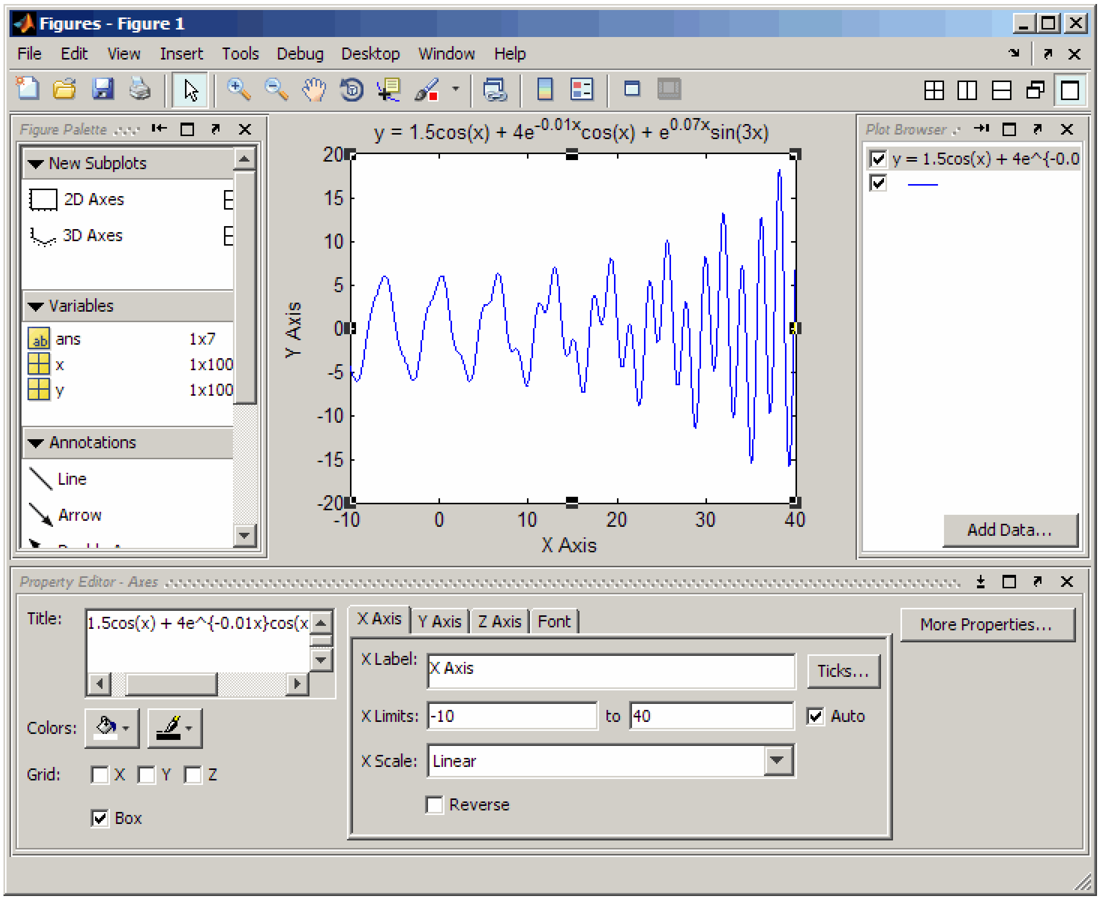
- Plot Browser — Select objects in the graphics hierarchy, control visibility, and add data to axes.
- Property Editor — Change key properties of the selected object. Click **More Properties** to access all object properties with the Property Inspector.

You can also control these components from the Command Window, by typing the following:

```
figurepalette
plotbrowser
propertyeditor
```

See the reference pages for `plottools`, `figurepalette`, `plotbrowser`, and `propertyeditor` for information on syntax and options.

The following picture shows a figure with all three plotting tools enabled.

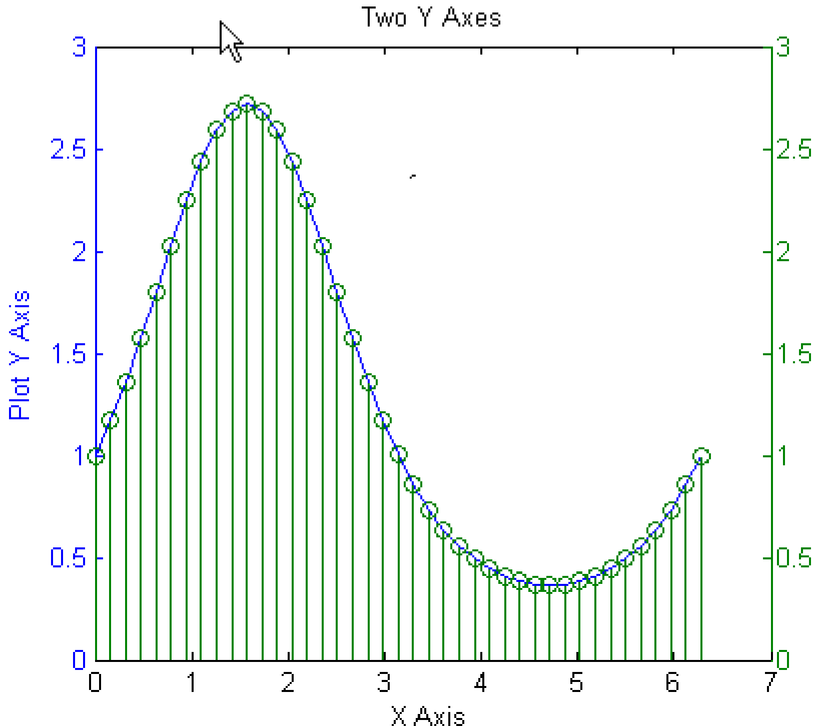


Using Plotting Tools and MATLAB Code

You can enable the plotting tools for any graph, even one created using MATLAB commands. For example, suppose you type the following code to create a graph:

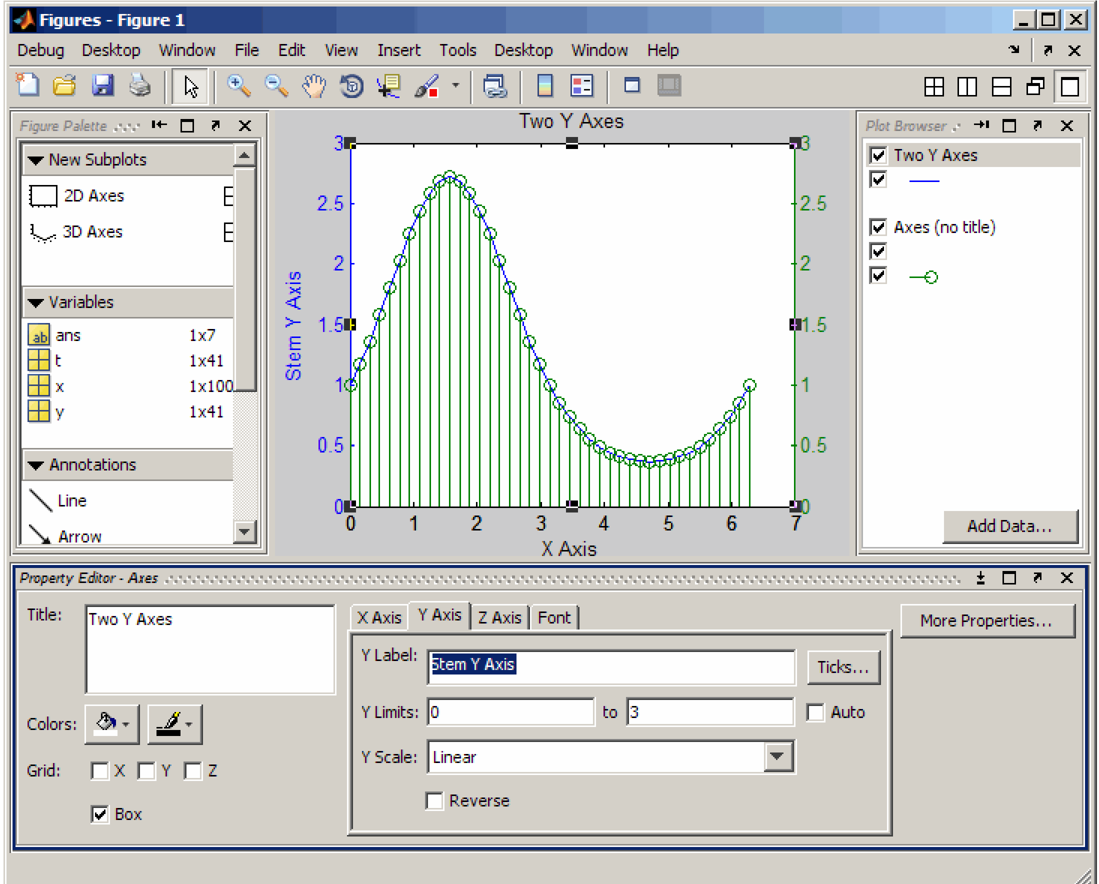
```
t = 0:pi/20:2*pi;
y = exp(sin(t));
plotyy(t,y,t,y,'plot','stem')
xlabel('X Axis')
ylabel('Plot Y Axis')
```

```
title('Two Y Axes')
```



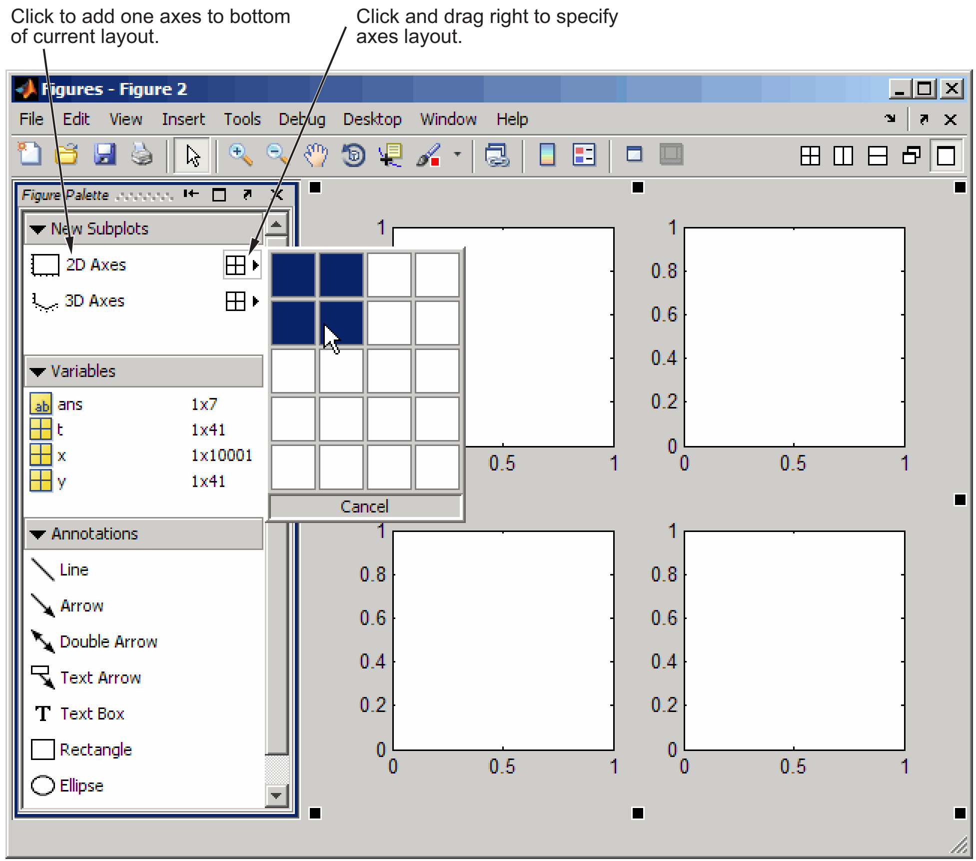
This graph contains two *y*-axes, one for each plot type (a lineseries and a stemseries). The plotting tools make it easy to select any of the objects that the graph contains and modify their properties.

For example, adding a label for the *y*-axis that corresponds to the stem plot is easily accomplished by selecting that axes in the Plot Browser and setting the **Y Label** property in the Property Editor (if you do not see that text field, stretch the Figures window to make it taller).



Arranging Graphs Within a Figure

You can place a number of axes within a figure by selecting the layout you want from the Figure Palette. For example, the following picture shows how to specify four 2-D axes in the figure.



Select the axes you want to target for plotting. You can also use the `subplot` function to create multiple axes.

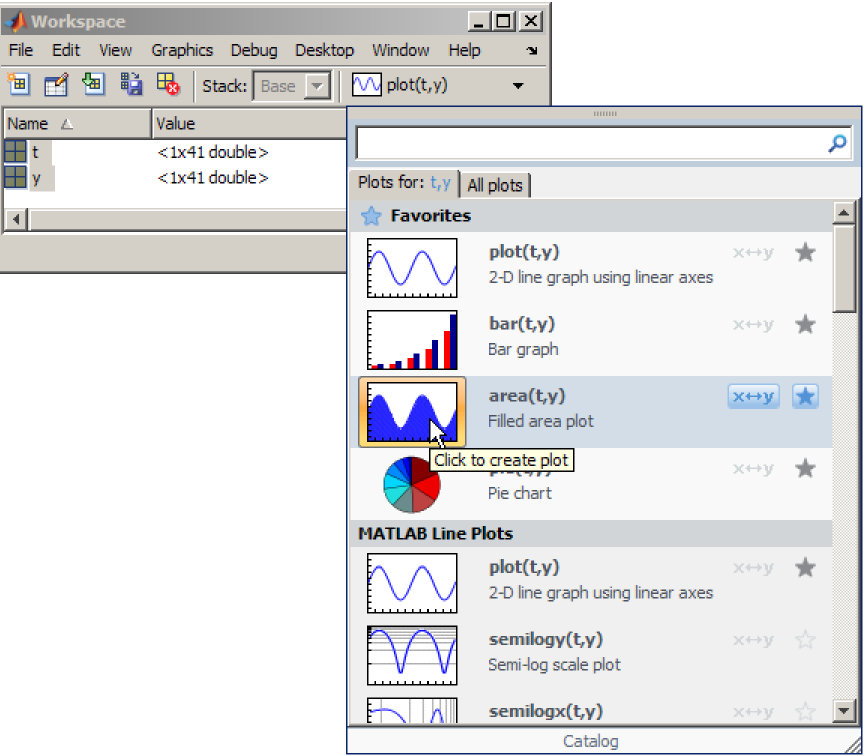
Choosing a Type of Graph to Plot

For details on the many kinds of 2-D and 3-D graphs you can plot, see "Types of MATLAB Plots" in the MATLAB Graphics documentation. Clicking a function name opens the function reference pages. Several desktop tools also summarize the types of graphs available to you and help you plot them quickly. These tools, the Plot Selector and the Plot Catalog, are described in the following sections.

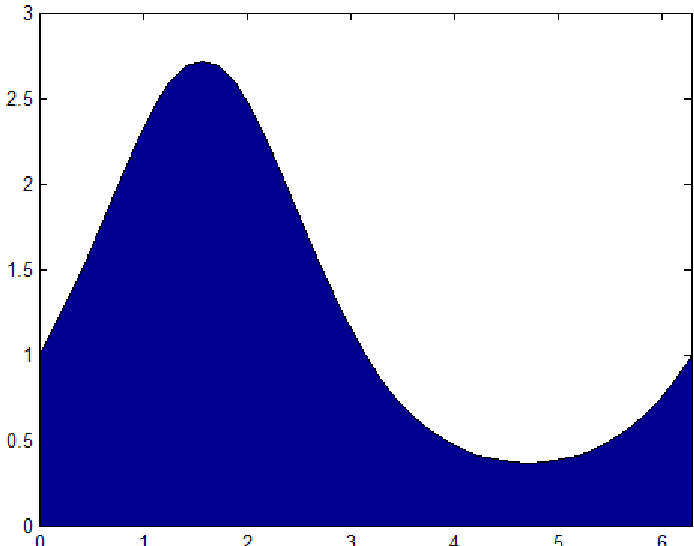
Creating Graphs with the Plot Selector

After you select variables in the Workspace Browser, you can create a graph of the data by clicking the Plot Selector plot(t,y) toolbar button. The Plot Selector icon depicts the type of graph it creates by default. The default graph reflects the variables you select and your history of using the tool. The Plot Selector icon changes to indicate the default type of graph along with the function's name and calling arguments. If you click the icon, the Plot Selector executes that code to create a graph of the type it displays. For example, when you select two vectors named `t` and `y`, the Plot Selector initially displays `plot(t,y)`.

If you click the down-arrow on the right side of the button, its menu opens to display all graph types compatible with the selected variables. The following figure shows the Plot Selector menu with an area graph selected. The graph types that the Plot Selector shows as available are consistent with the variables (`t` and `y`) currently selected in the Workspace Browser.



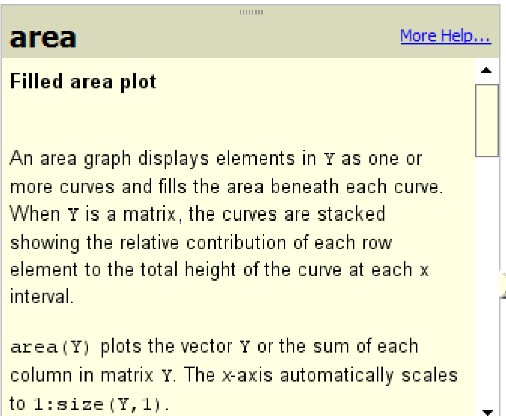
Releasing the mouse button over the highlighted icon creates an area graph.



You can see how the graph is created because the code the Plot Selector generates executes in the Command Window:

```
>> area(t,y,'DisplayName','t,y');figure(gcf)
```

You can also use the Plot Selector to get help for graphing functions. A scrolling yellow window pops up when you hover the mouse pointer over a Plot Selector menu item. The help window contains syntax descriptions for the function you point at. To open the entire function reference page in a Help Browser window, click the **More Help** link at the top right of the pop-up window, an example of which (for `area`) appears in the following figure.

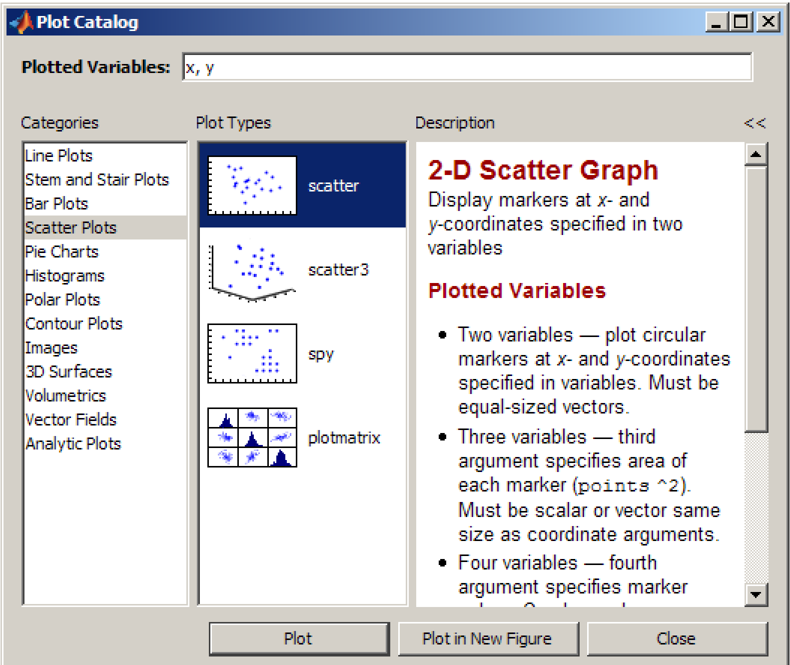


To keep the help text visible, click just inside the top edge of the pop-up help window and drag it to another location on your screen. Close the window by clicking on the X in its upper left corner.

For more information about using the Plot Selector, see "Creating Plots from the Workspace Browser".

Creating Graphs with the Plot Catalog

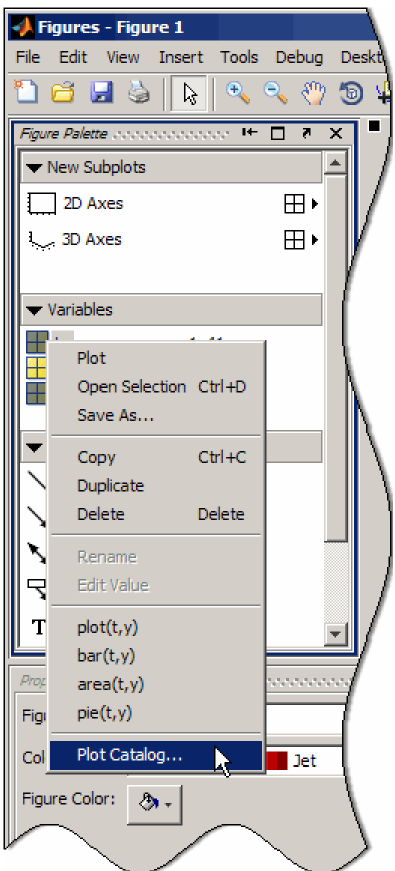
Instead of the Plot Selector, you can use the Plot Catalog tool to browse graph types and create plots of selections of data. The Plot Catalog shows all graph types, categorizes them, and provides short descriptions of categories and plot types. It also lets you edit the list of variables before you create a plot. The Plot Catalog looks like this (when you select the **Scatter Plots** category).



Open the Plot Catalog in any of the following ways:

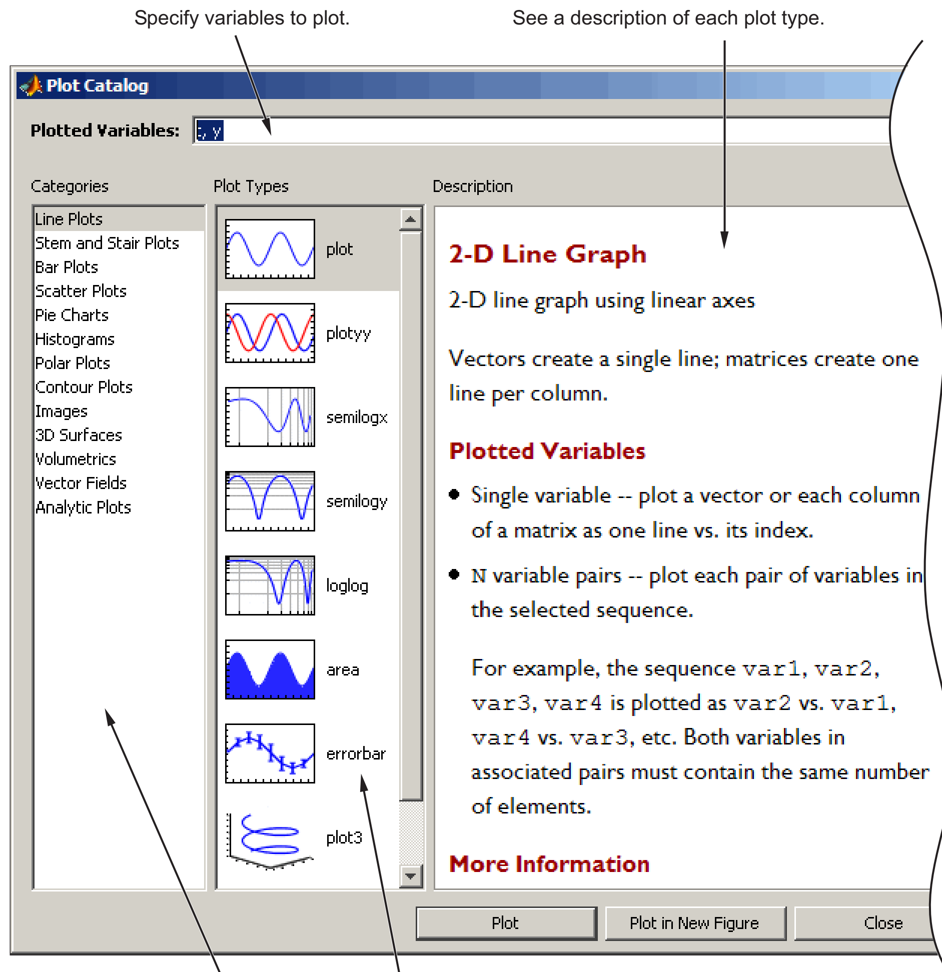
- Open the Plot Selector menu and click the **Catalog** link at the bottom of the menu.
- In the Workspace browser, right-click a selected variable and choose **Plot Catalog** from the context menu.
- In the Variable Editor, select the values you want to graph, right- click the selection you just made, and choose **Plot Catalog** from the context menu.
- If you are using the Figure Palette (a component of the Plotting Tools), right-click a selected variable and choose **Plot Catalog** from the context menu

The following illustration shows how you can open the plot catalog from the Figure Palette after selecting two numeric variables:



The menu of plot types above the **Plot Catalog** item is the same as your current Plot Selector list of "favorites." This means that you can specify these items to be the kinds of graphs that you regularly use. See "Working with the Plot Selector GUI" for more information on managing a list of favorite graph types.

After you select **Plot Catalog**, the Plot Catalog opens in a new, undocked window with the selected variables, ready for you to choose a type of graph to create. Select a plot category from the first column, then a graph type from the second column, and click **Plot** or **Plot in New Figure**. You can override the selected variables by typing other variable names or MATLAB expressions in the **Plotted Variables** edit field.



For more information, see "Example — Plotting from the Figure Palette".

Editing Plots

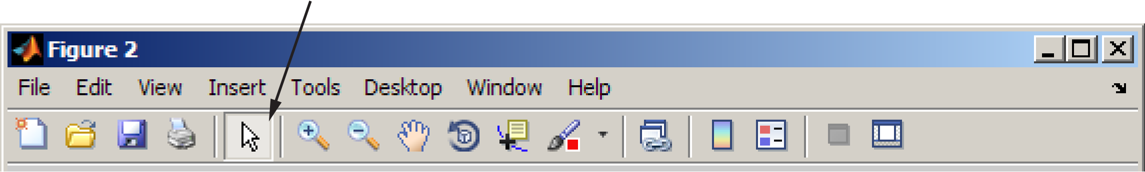
In this section...
"Plot Edit Mode" on page 3-23
"Using Functions to Edit Graphs" on page 3-28

Plot Edit Mode

Plot edit mode lets you select specific objects in a graph and enables you to perform point-and-click editing of most of them.

Enabling Plot Edit Mode

To enable plot edit mode, click the arrowhead in the figure toolbar:

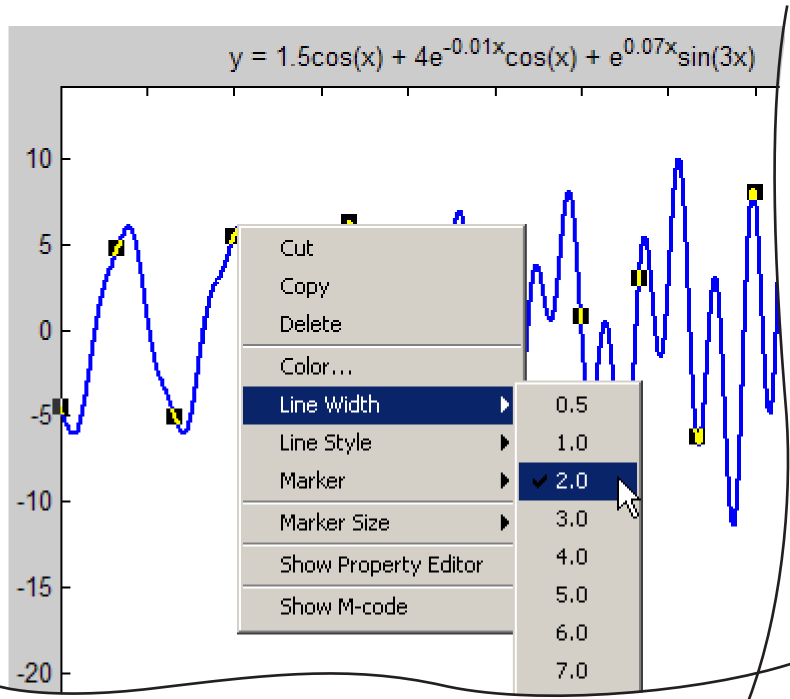


You can also select **Edit Plot** from the figure **Tools** menu.

Setting Object Properties

After you have enabled plot edit mode, you can select objects by clicking them in the graph. Selection handles appear and indicate that the object is selected. Select multiple objects using **Shift**+click.

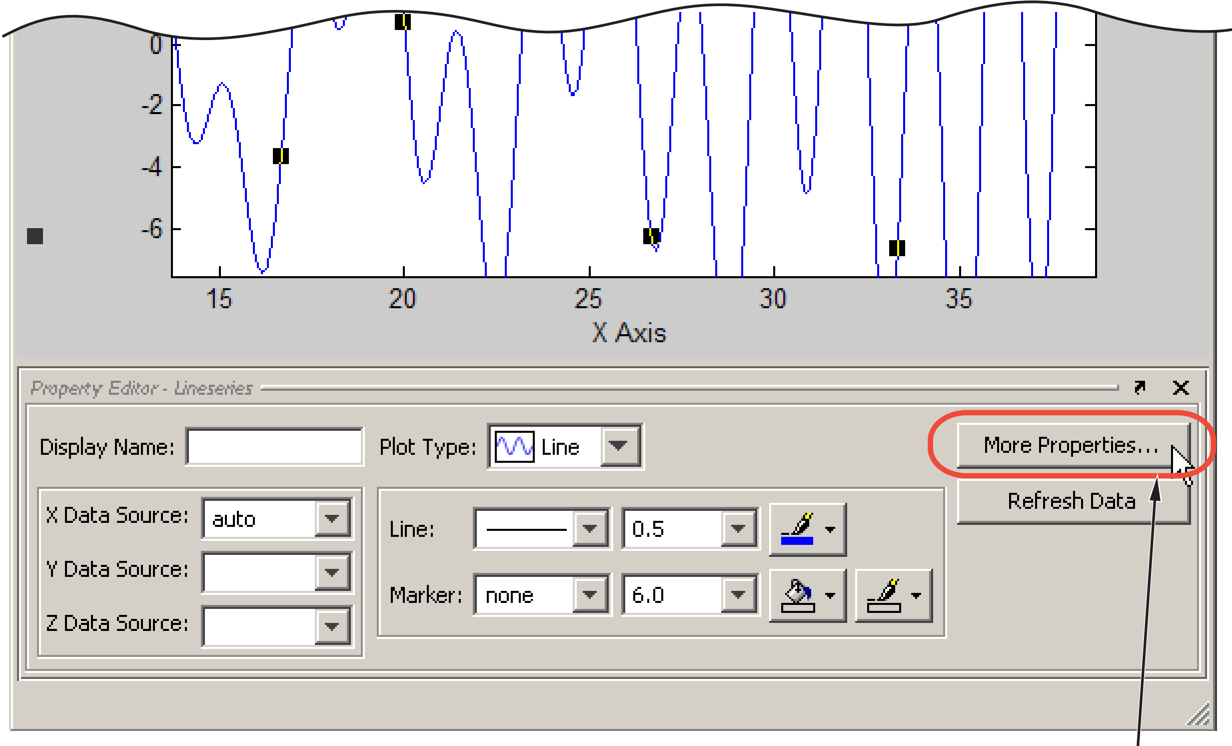
Right-click with the pointer over the selected object to display the object's context menu:



The context menu provides quick access to the most commonly used operations and properties.

Using the Property Editor

In plot edit mode, double-clicking an object in a graph opens the Property Editor GUI with that object's major properties displayed. The Property Editor provides access to the most used object properties. When you select an object, it updates to display the properties of whatever object you select.



Click to display Property Inspector

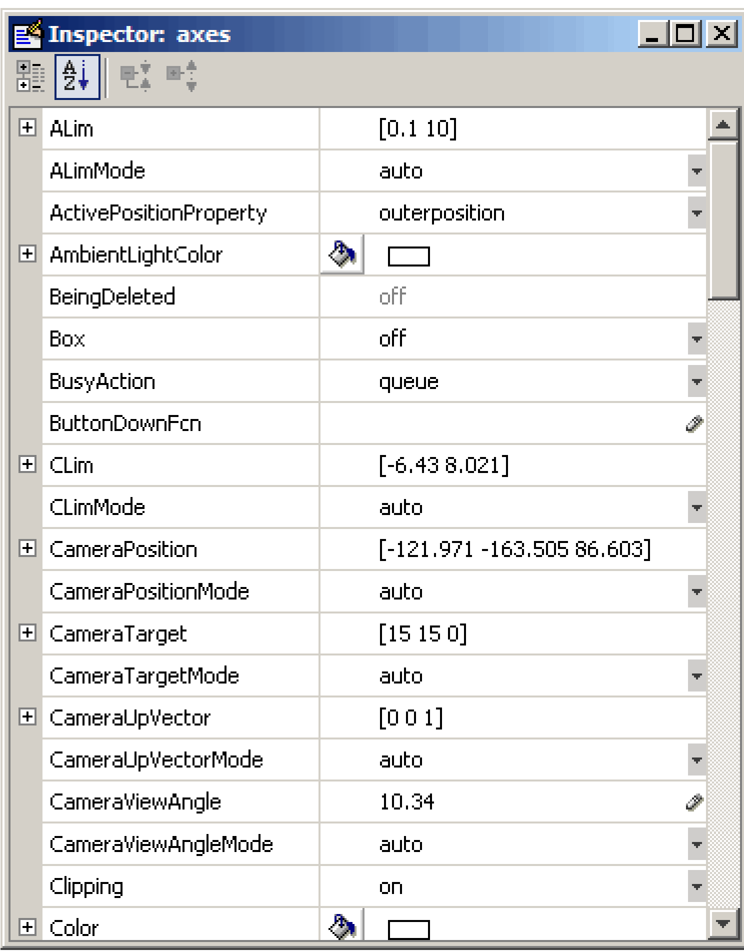
Accessing Properties with the Property Inspector

The *Property Inspector* is a tool that enables you to access most Handle Graphics properties and other MATLAB objects. If you do not find the property you want to set in the Property Editor, click the **More Properties** button to display the Property Inspector. You can also use the `inspect` command to start the Property Inspector. For example, to inspect the properties of the current axes, type

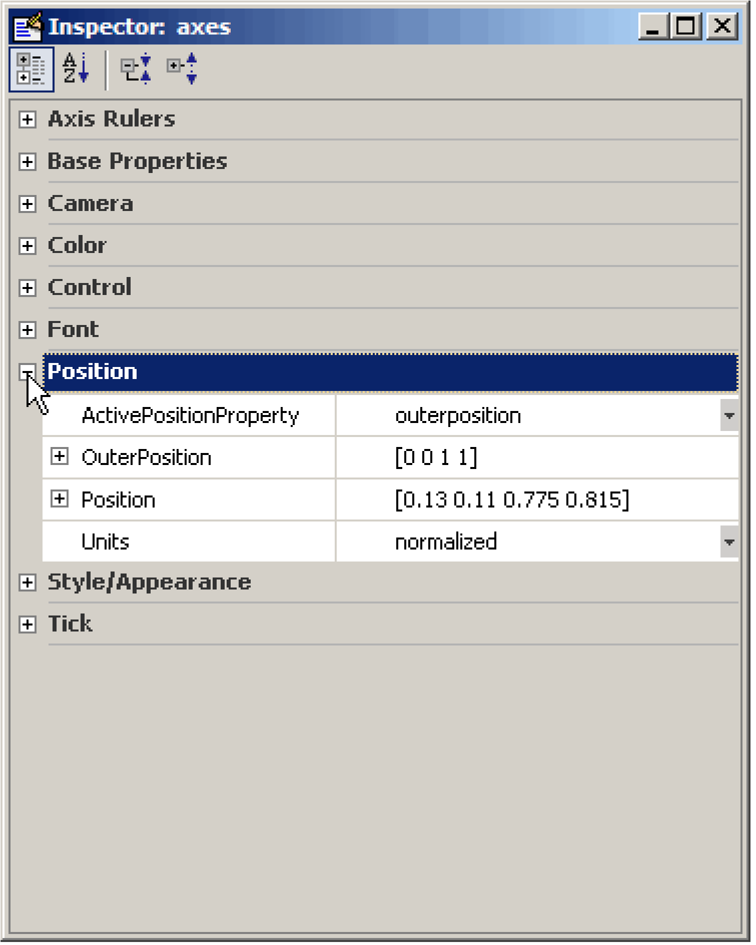
```
inspect(gca)
```

The following picture shows the Property Inspector displaying the properties of a graph's axes. It lists each property and provides a text field or other appropriate device (such as a color picker) from which you can set the value of the property.

As you select different objects, the Property Inspector updates to display the properties of the current object.



The Property Inspector lists properties alphabetically by default. However, you can group Handle Graphics objects, such as axes, by categories which you can reveal or close in the Property Inspector. To do so, click the icon at the upper left, then click the + next to the category you want to expand. For example, to see the position-related properties, click the + to the left of the **Position** category.



The **Position** category opens and the + changes to a - to indicate that you can collapse the category by clicking it.

Using Functions to Edit Graphs

If you prefer to work from the MATLAB command line, or if you are creating an M-file, you can use MATLAB commands to edit the graphs you create. You can use the `set` and `get` commands to change the properties of the objects in a graph. For more information about using graphics commands, see "Understanding Handle Graphics Objects" on page 3-85.

Some Ways to Use Plotting Tools

In this section...

"Plotting Two Variables with Plotting Tools" on page 3-29
"Changing the Appearance of Lines and Markers" on page 3-32
"Adding More Data to the Graph" on page 3-33
"Changing the Type of Graph" on page 3-36
"Modifying the Graph Data Source" on page 3-38

Plotting Two Variables with Plotting Tools

Suppose you want to graph the function $y = x^3$ over the x domain -1 to 1. The first step is to generate the data to plot.

It is simple to evaluate a function like this because the MATLAB software can distribute arithmetic operations over all elements of a multivalued variable.

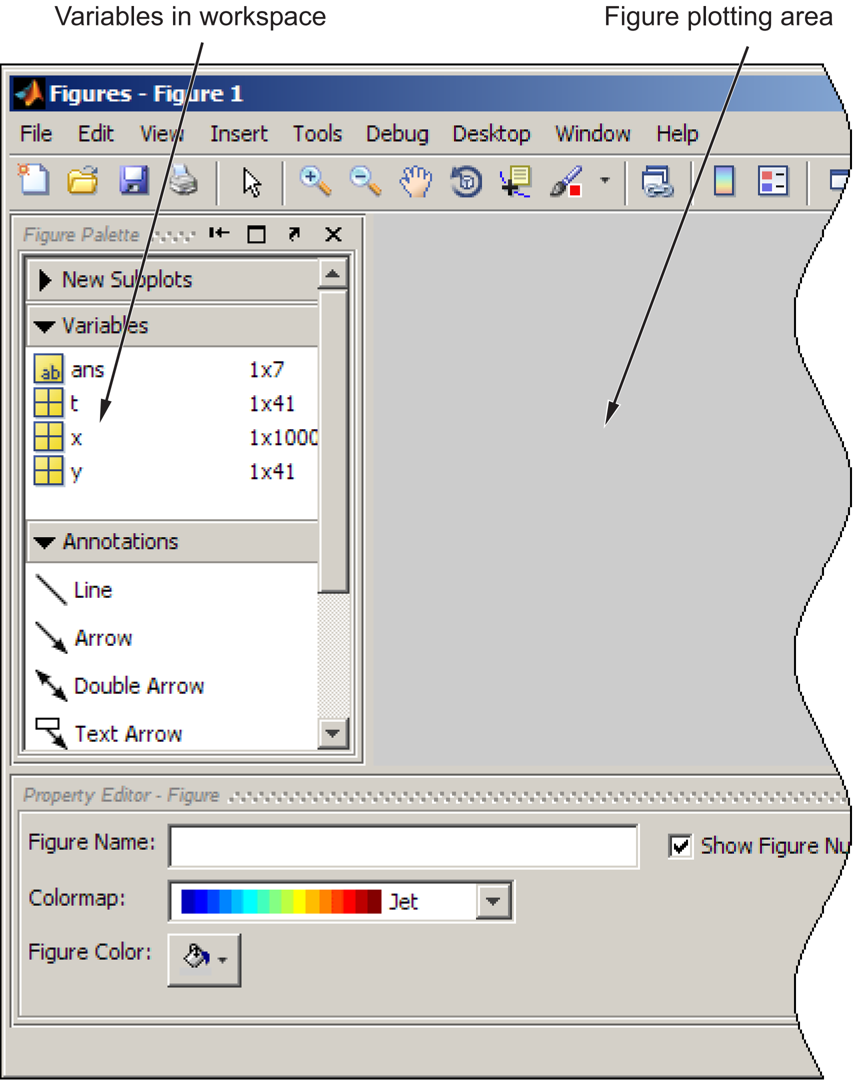
For example, the following statement creates a variable `x` that contains values ranging from -1 to 1 in increments of 0.1 (you could also use the `linspace` function to generate data for `x`). The second statement raises each value in `x` to the third power and stores these values in `y`:

```
x = -1:.1:1; % Define the range of x
y = x.^3;    % Raise each element in x to the third power
```

Now that you have generated some data, you can plot it using the MATLAB plotting tools. To start the plotting tools, type

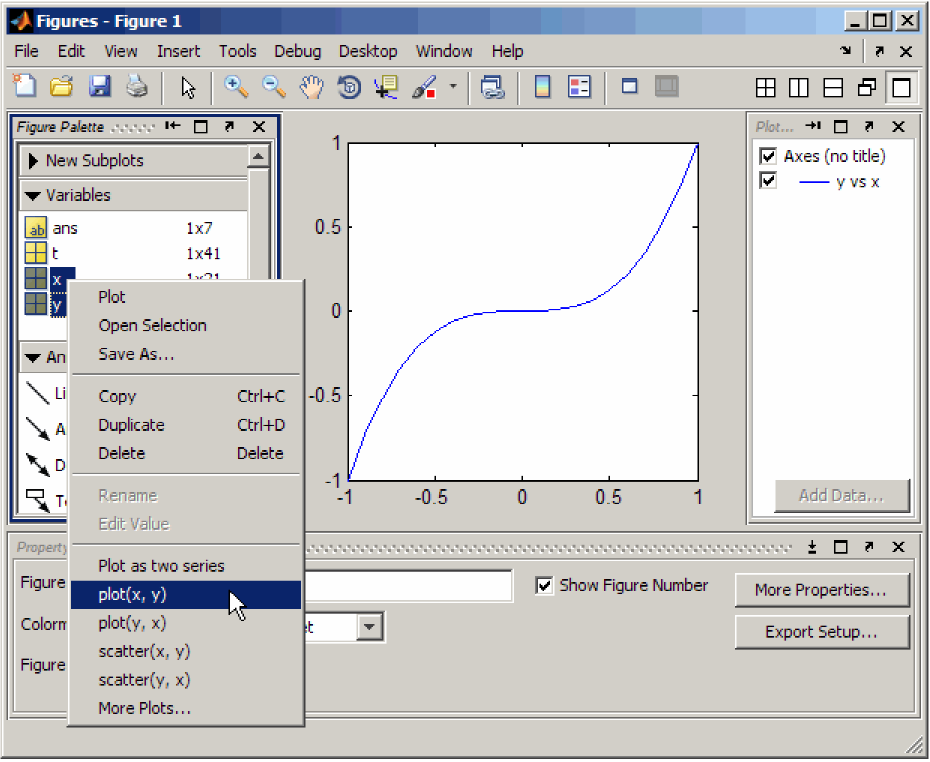
```
plottools
```

A figure displays with plotting tools attached.


Variables in workspace
Figure plotting area
Figures - Figure 1
File Edit View Insert Tools Debug Desktop Window Help
Figure Palette
New Subplots
Variables
ans 1x7
t 1x41
x 1x1000
y 1x41
Annotations
Line
Arrow
Double Arrow
Text Arrow
Property Editor - Figure
Figure Name:
Show Figure Nu
Colormap:
Jet
Figure Color:

Note When you invoke `plottools`, the set of plotting tools you see and their relative positions depend on how they were configured the last time you used them. Also, sometimes when you dock and undock figures with plotting tools attached, the size or proportions of the various components can change, and you may need to resize one or more of the tool panes.

A simple line graph is a suitable way to display `x` as the independent variable and `y` as the dependent variable. To do this, select both variables (click to select, and then **Shift**+click or **Ctrl**+click if variables are not contiguous to select again), and then right-click to display the context menu.

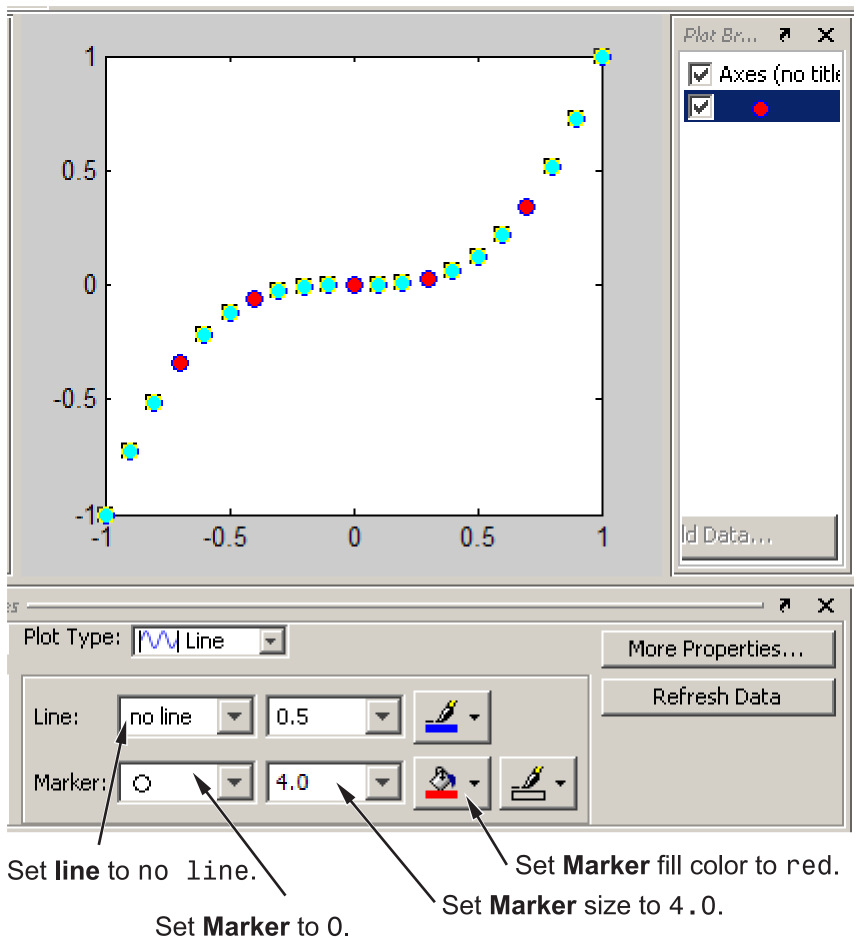


Select **plot(x, y)** from the menu. The line graph plots in the figure area. The black squares indicate that the line is selected and you can edit its properties with the Property Editor.

Changing the Appearance of Lines and Markers

Next, change the line properties so that the graph displays only the data point. Use the Property Editor to set following properties:

- Line to no line
- Marker to o (circle)
- Marker size to 4.0
- Marker fill color to red



Adding More Data to the Graph

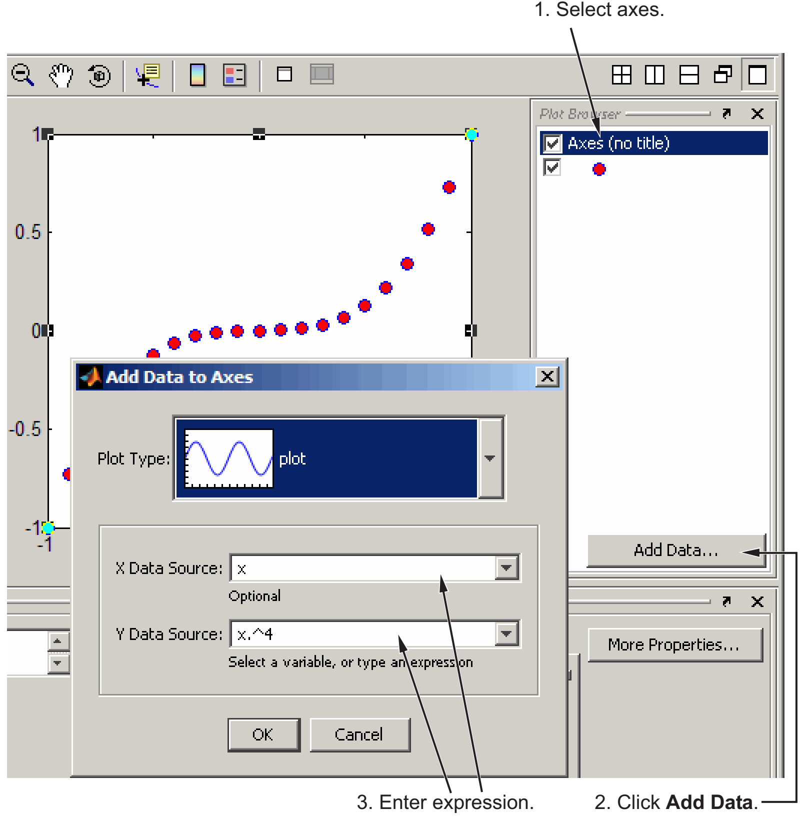
You can add more data to the graph by defining more variables or by specifying a MATLAB expression to generate data for the plot. This second approach makes it easy to explore variations of the data already plotted.

To add data to the graph, select the axes in the Plot Browser and click the **Add Data** button. When you are using the plotting tools, new data plots are always added to the existing graph, instead of replacing the graph, as it

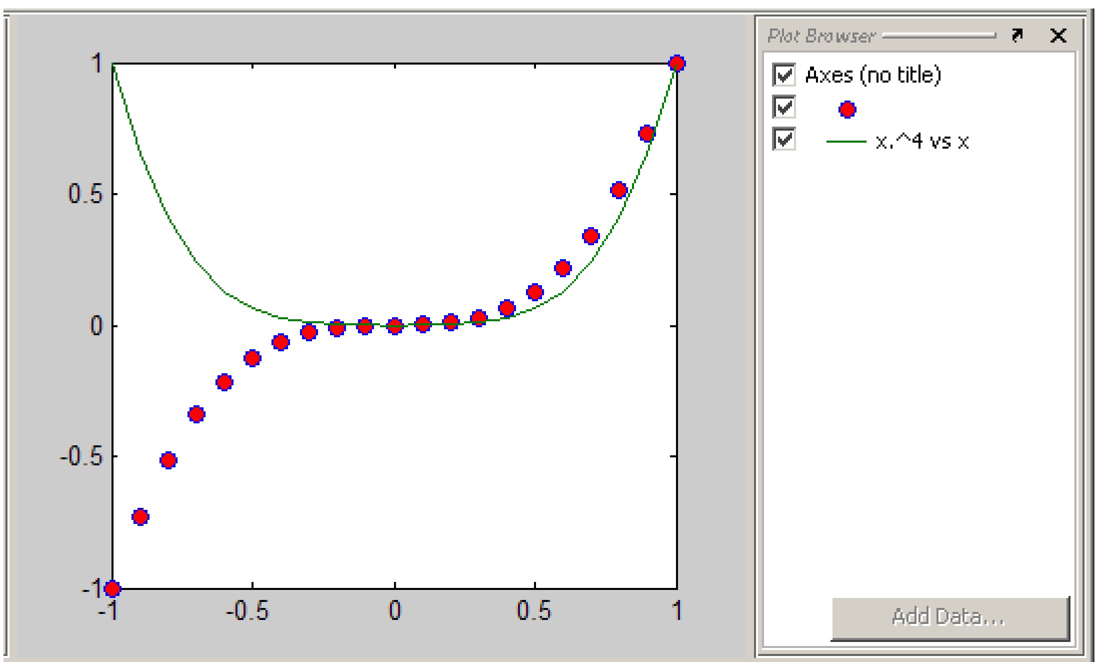
would if you issued repeated plotting commands. Thus, the plotting tools are in a `hold on` state.

To add data using the Plot Browser:

1. Click the **Edit Plot** tool .
2. Select the axes to which you wish to add data;
handles appear around it.
3. Click the **Add Data** button in the Plot Browser;
the Add Data to Axes dialog box opens.
4. Select a plot type from the **Plot Type** drop-down menu.
5. Select a variable or type an expression for **X Data Source**.
6. Select a variable or type an expression for **Y Data Source**.
7. Click **OK**;
a plot of the data you specified is added to the axes.



The preceding figure shows how to use the Add Data to Axes dialog box to create a line plot of $y = x^4$, which is added to the existing plot of $y = x^3$. The resulting plot appears with the Plot Browser, as shown in the following figure:



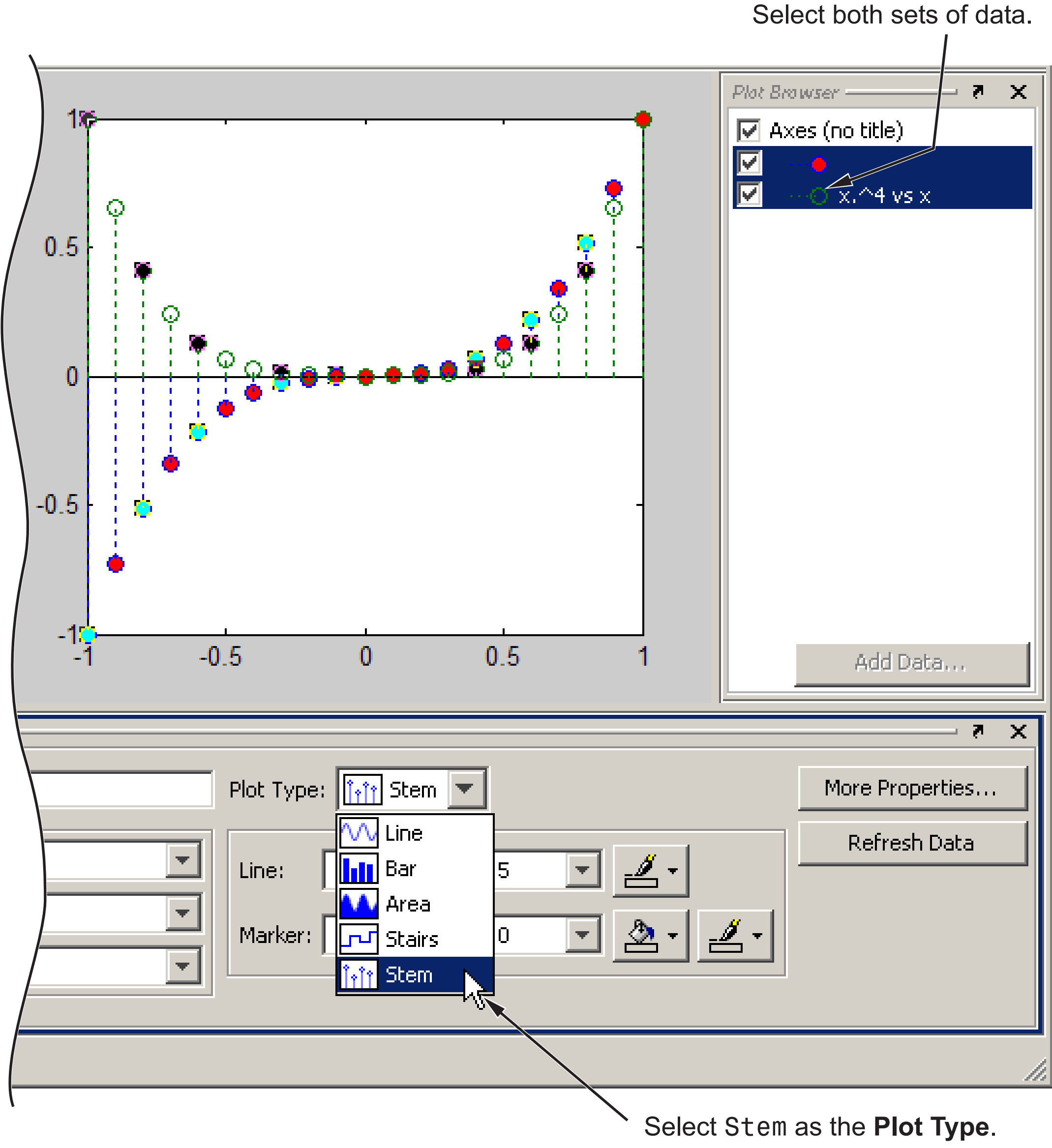
Changing the Type of Graph

The plotting tools enable you to easily view your data with a variety of plot types. The following picture shows the same data as above converted to stem plots. To change the plot type,

1 Select both plotted series in the Plot Browser or **Shift**+click to select them in the plot itself.

2 Select short dashes from the **Line** drop-down menu in the Property Inspector; the line type of both series changes.

3 Select **Stem** from the **Plot Type** menu.



Select both sets of data.
Plot Browser
Axes (no title)
x.^4 vs x
Add Data...
1
0.5
0
-0.5
-1
-1
-0.5
0
0.5
1
Plot Type:
Stem
Line
Bar
Area
Stairs
Stem
Line:
Marker:
More Properties...
Refresh Data
Select Stem as the Plot Type.

Modifying the Graph Data Source

You can link graph data to variables in your workspace. When you change the values contained in the variables, you can then update the graph to use the new data without having to create a new graph. (See also the `refresh` function.)

1 Define 50 points between -3π and 3π and compute their sines and cosines:

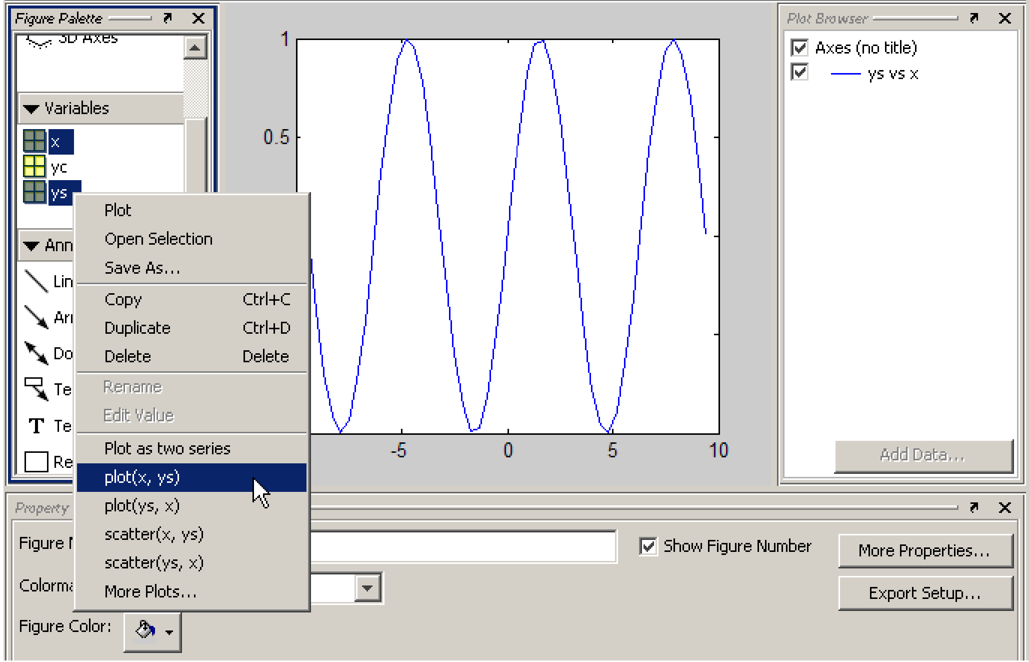
```
x = linspace(-3*pi,3*pi,50);
ys = sin(x);
yc = cos(x);
```

2 Using the plotting tools, create a graph of `ys = sin(x)`:

```
figure
plottools
```

3 In the Figure Palette, alternate-click to select *x* and *ys* in the **Variable** pane.

4 Right-click either selected variable and choose **plot(x, ys)** from the context menu, as the following figure shows.

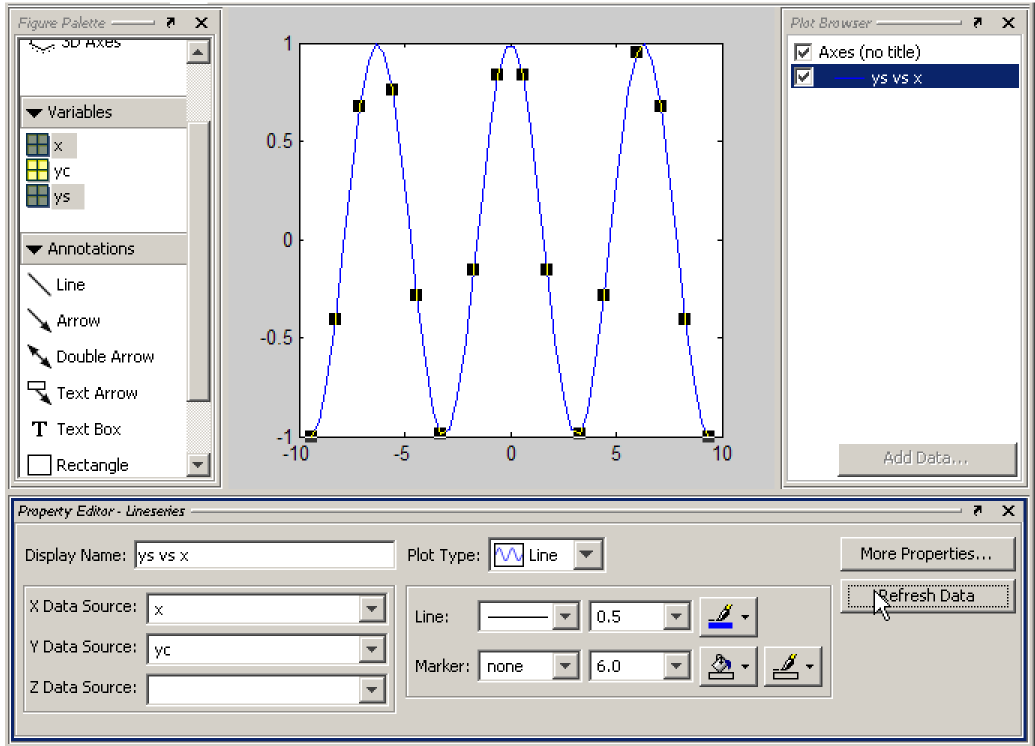


You can use the Property Editor to change the data that this plot displays:

1 Select the line `ys vs x` in the Plot Browser or by clicking it.

2 In the Property Editor, select `yc` in the **Y Data Source** drop-down menu.

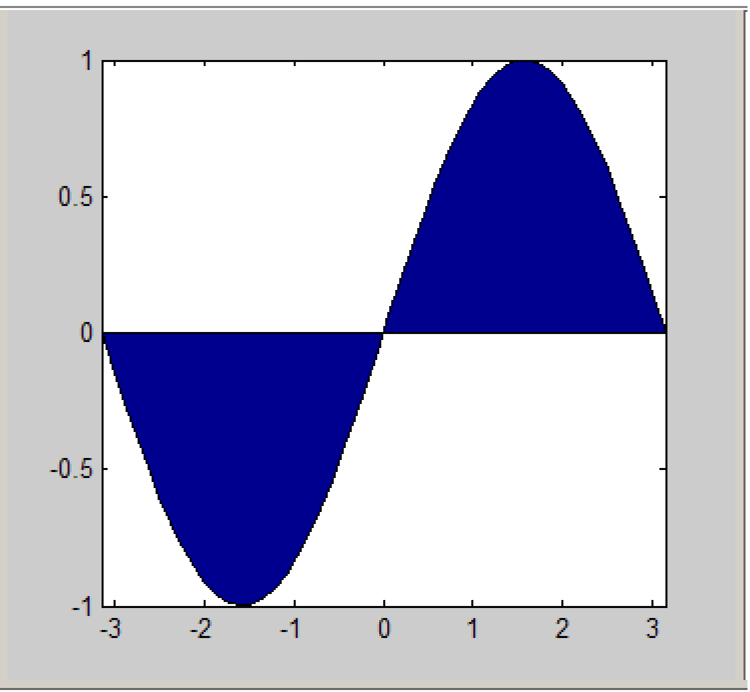
3 Click the **Refresh Data** button;
the plot will change to display a plot of `yc vs x`.



Providing New Values for the Data Source

Data values that define the graph are copies of variables in the base workspace (for example, `x` and `y`) to the `XData` and `YData` properties of the plot object (for example, a lineseries). Therefore, in addition to being able to choose new data sources, you can assign new values to workspace variables in the Command Window and click the **Refresh Data** button to update a graph to use the new data.

```
x = linspace(-pi,pi,50); % Define 50 points between -π and π
y = sin(x);
area(x,y)  % Make an area plot of x and y
```



Now, recalculate `y` at the command line:

```
y = cos(x)
```

Select the blue line on the plot. Select, `x` as the **X Data Source**, `y` as the **Y Data Source**, and click **Refresh Data**. The graph's `XData` and `YData` are replaced, making the plot look like this.

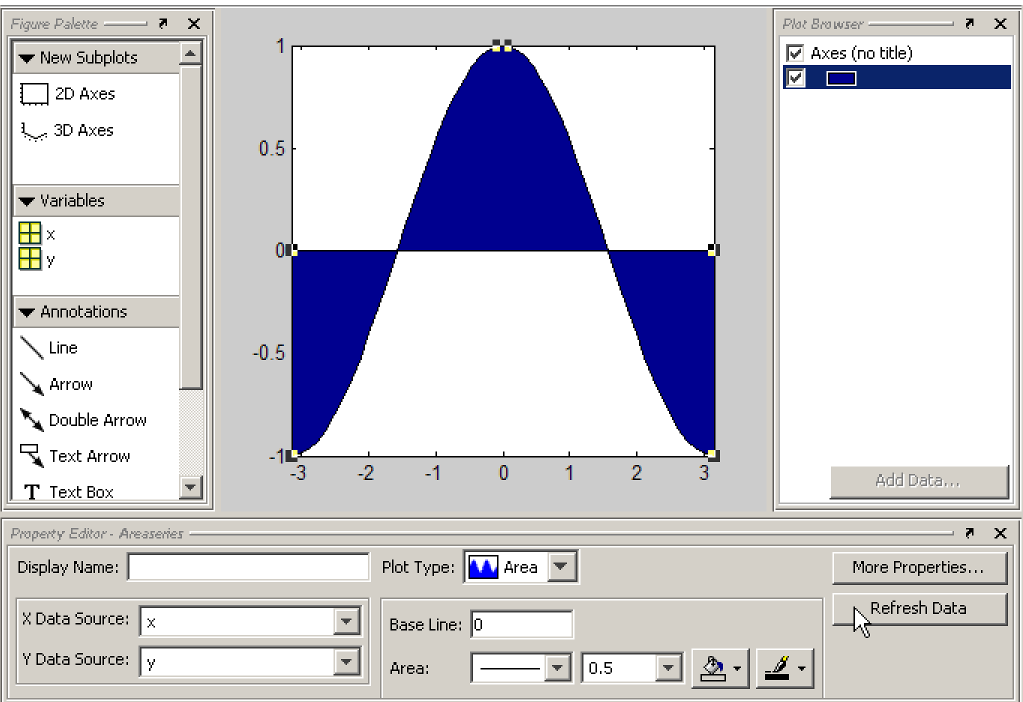


Figure Palette
New Subplots
2D Axes
3D Axes
Variables
x
y
Annotations
Line
Arrow
Double Arrow
Text Arrow
Text Box
Plot Browser
Axes (no title)
Add Data...
Property Editor - Areaseries
Display Name:
Plot Type:
Area
More Properties...
X Data Source:
x
Y Data Source:
y
Base Line:
0
Area:
0.5
Refresh Data

Preparing Graphs for Presentation

In this section...

"Annotating Graphs for Presentation" on page 3-43

"Printing the Graph" on page 3-48

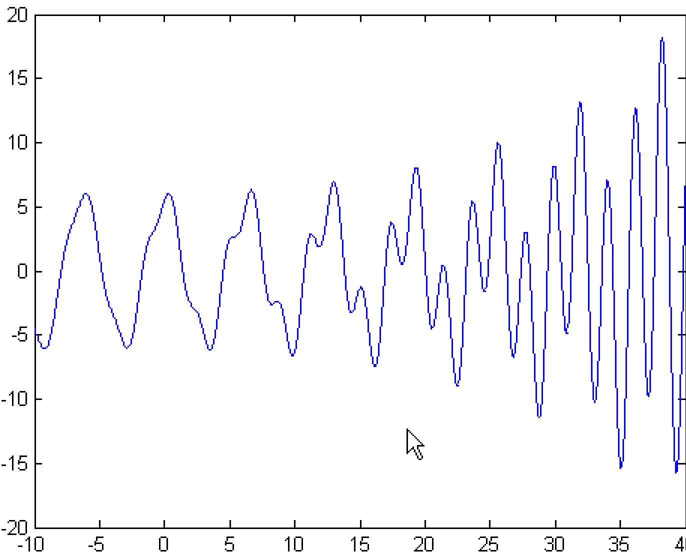
"Exporting the Graph" on page 3-52

Annotating Graphs for Presentation

Suppose you plot the following data and want to create a graph that presents certain information about the data:

```
x = -10:.005:40;
y = [1.5*cos(x)+4*exp(-.01*x).*cos(x)+exp(.07*x).*sin(3*x)];
plot(x,y)
```

This figure shows the graph created by the previous code.

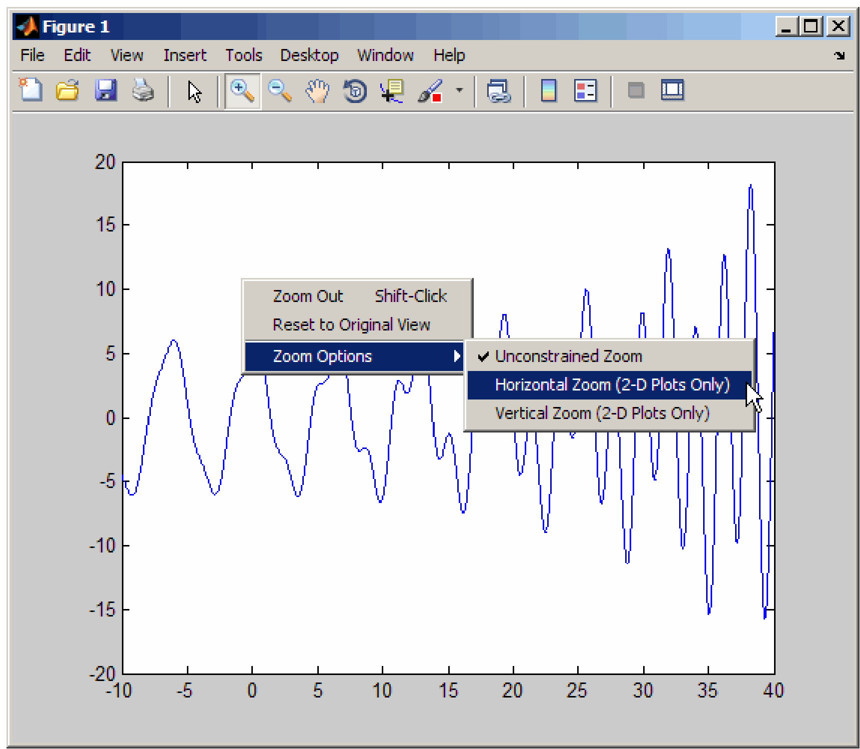


Now, suppose you want to save copies of the graph by

- Printing the graph on a local printer so you have a copy for your notebook
- Exporting the graph to an Encapsulated PostScript® (EPS) file to incorporate into a word processor document

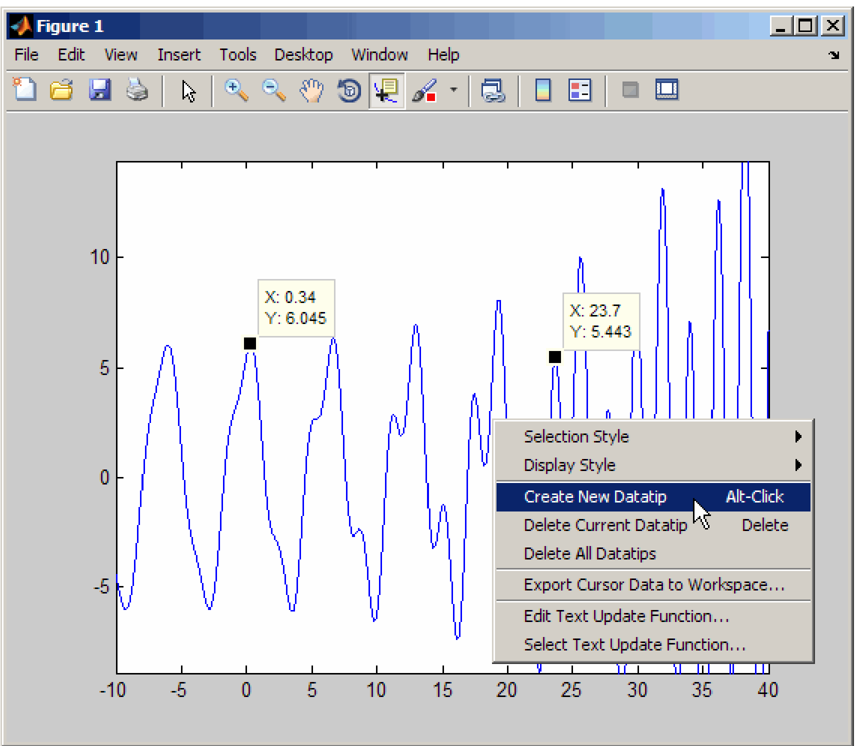
To obtain a better view, zoom in on the graph using horizontal zoom.

Enable zoom mode by clicking the **Zoom** tool on the figure toolbar, and then right-click to display the context menu. Select **Horizontal Zoom (2-D Plots Only)** from **Zoom Options**. You can reverse your zoom direction by doing **Shift+left-click**, or using the context menu.

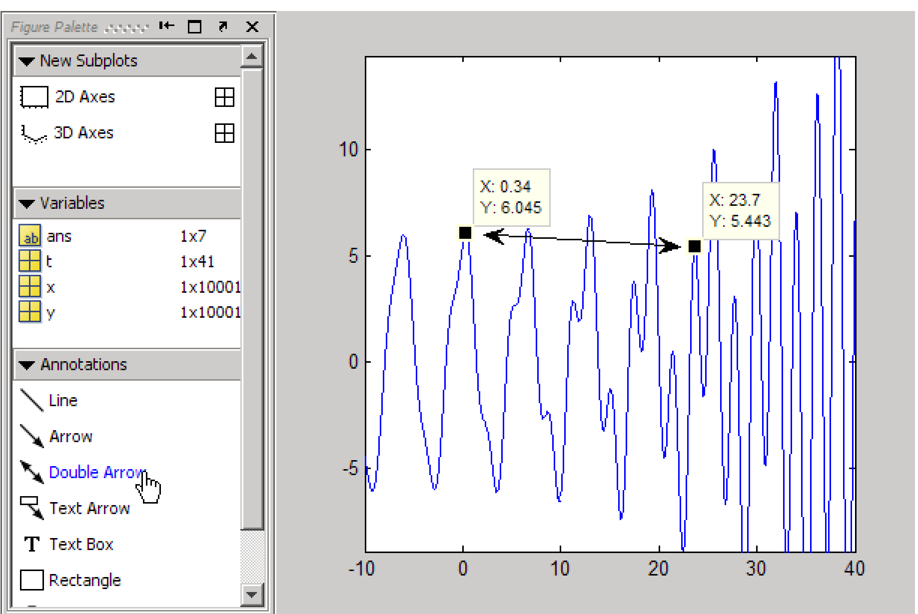


Left-click to zoom in on a region of the graph and use the **Pan** tool to position the points of interest where you want them on the graph.

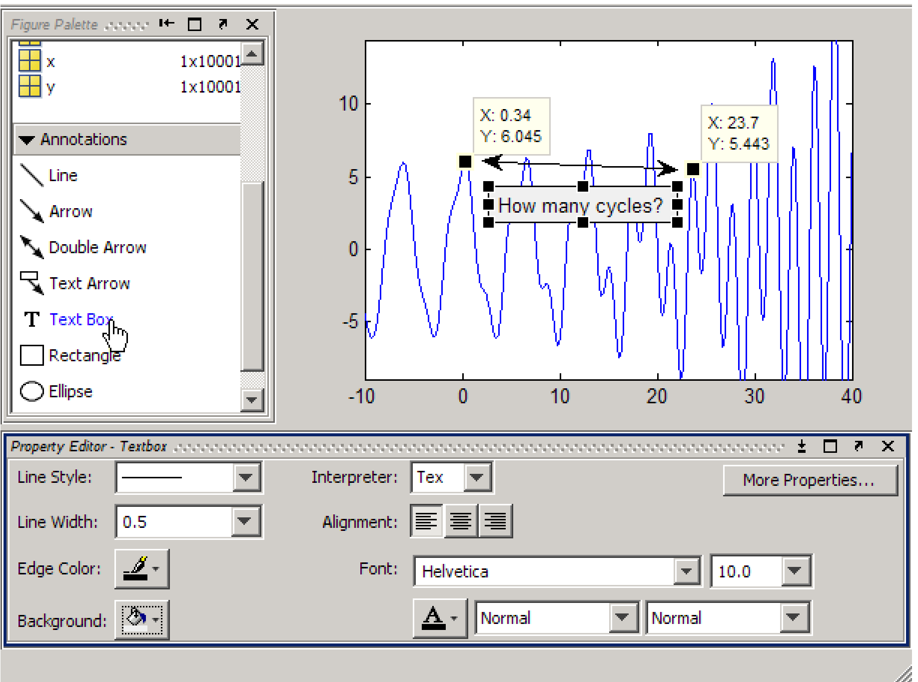
Label some key points with data tips using the **Data Cursor** tool . Left-clicking the line moves the last datatip you created to where you just clicked. To create a new datatip, press **Alt**+click or use the tool's context menu. See "Data Cursor — Displaying Data Values Interactively" in the MATLAB Graphics documentation for more information on using datatips.



Next, use the Figure Palette to annotate the plot. Choose the Double arrow tool in the Annotations section to draw a line between two datatips, as shown in the following figure.



Now, add a text box, also using the Figure Palette. You may have to scroll to see the text box icon. Drag out a box, and then type into it. You can stretch or shrink the box with its handles, and center the text with the Property Editor while the text box is selected. You can also use the Property Editor to change the text font, size, style, color, and also the text box line and background colors.

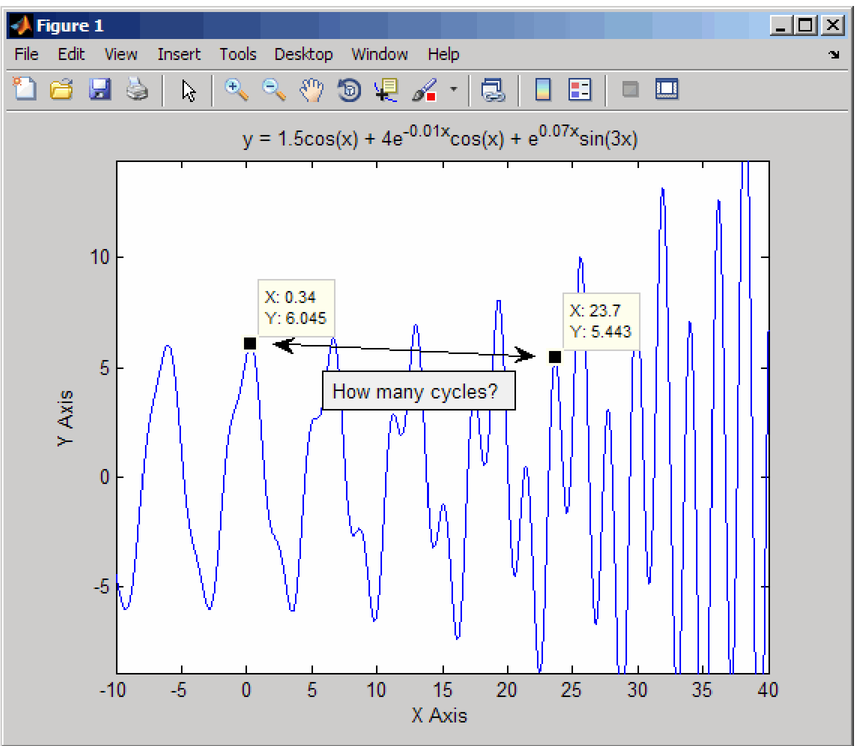


Finally, add text annotations, axis labels, and a title. You can add the title and axis labels using the following commands:

```
title ('y = 1.5cos(x) + 4e^{-0.01x}cos(x) + e^{0.07x}sin(3x)')
xlabel('X Axis')
ylabel('Y Axis')
```

Note The text string passed to `title` uses $\TeX$ syntax to produce the exponents. See "Information About Using $\TeX$" in the Text Properties reference page for more about using $\TeX$ syntax to produce mathematical symbols.

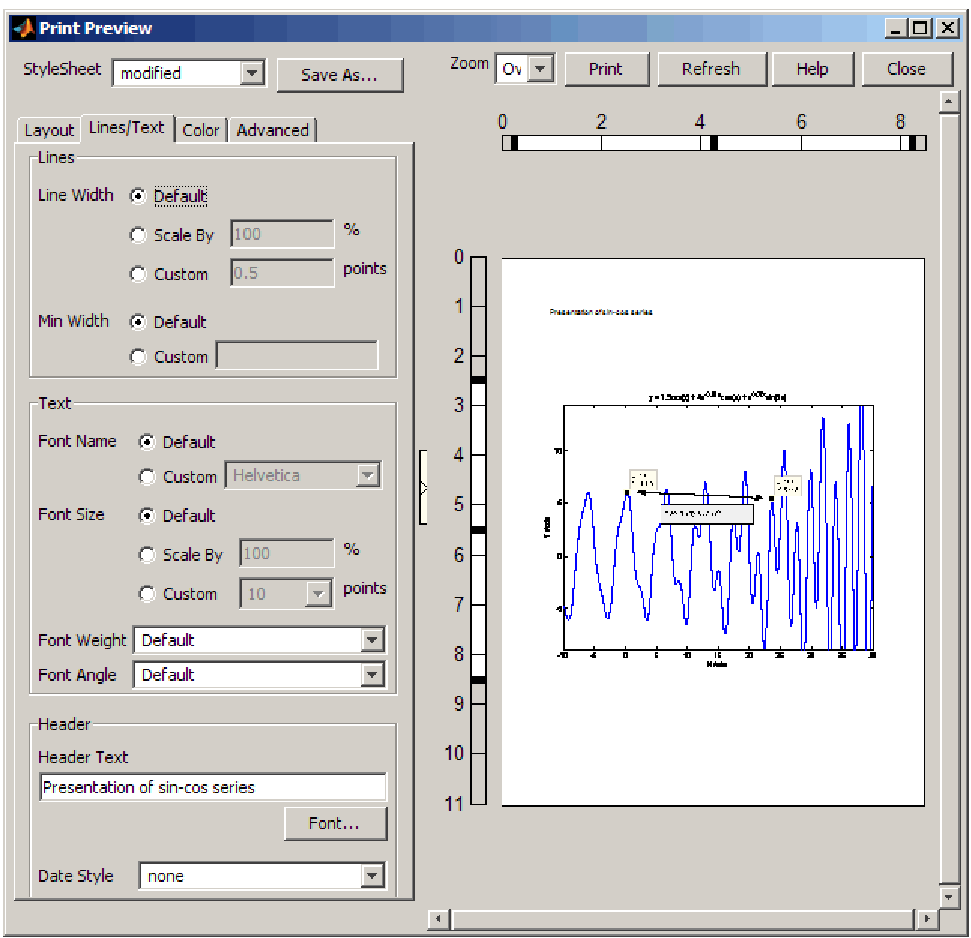
You can also add these annotations by selecting the axes and typing the above strings into their respective fields in the Property Editor. The graph is now ready to print and export.



Printing the Graph

Before printing the graph, select **File > Print Preview** to view and modify how the graph will be laid out on the page. The Print Preview window opens, containing a tabbed control panel on its left side and a page image on its right side.

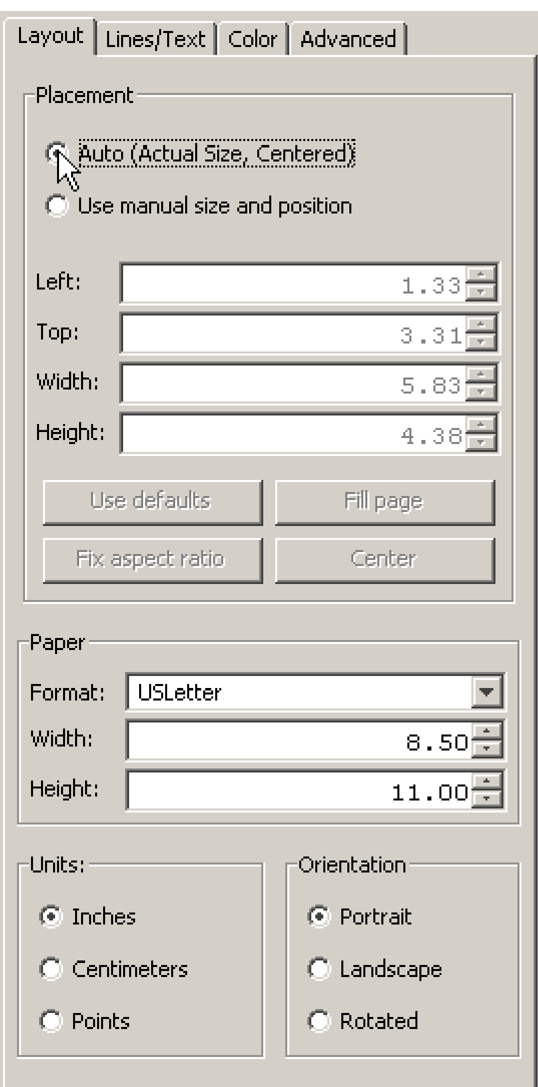
- Click the **Lines/Text** tab, and enter a line of text in the **Header Text** edit field that you want to place at the top of the page. You can change the font, style, and size of the header by clicking the **Font** button beneath the text field, and also use the **Date Style** drop-down list to specify a date format to add the current date/time to the header.



- The rulers along the left and top sides of the preview pane contain three black handlebars. The outside handlebars let you stretch one edge of the plot, leaving the other edges in place. The inner handlebars let you move

the plot up and down or left and right without stretching it. Using them does not affect the figure itself, only the printed version of it.

- You can also change the size and position of the plot on the page using the buttons and edit boxes on the **Layout** tab. You can revert to the original configuration by clicking the **Auto (Actual Size, Centered)** option button, and correct stretching and shrinking by clicking **Fix Aspect Ratio**. The following picture shows the **Layout** tab in Auto configuration.



- By default, the locations of the axes tick marks are recalculated because a printed graph is normally larger than the one displayed on your monitor. However, you can keep your graph's tick marks and limits when printing it by clicking the **Advanced** tab and selecting **Keep screen limits and ticks**.

- When you are ready to print your plot, click **Print** in the right pane. You can also click **Close** to accept the settings and dismiss the dialog box. Later, you can print the figure as you previewed it using **Print** on the figure's **File** menu. Both methods will open a standard Print dialog box, and will produce the same printed results.

Note There is no way to cancel a print preview; any changes you make will take effect if you print the figure. If you want to revert to a default page layout, you can generally accomplish this by selecting either the **Use Defaults** button or the **Auto (Actual Size, Centered)** option button on the **Layout** tab, although this will not affect every setting you can make.

The Print Preview dialog box provides many other options for controlling how printed graphs look. Click its **Help** button for more information.

Exporting the Graph

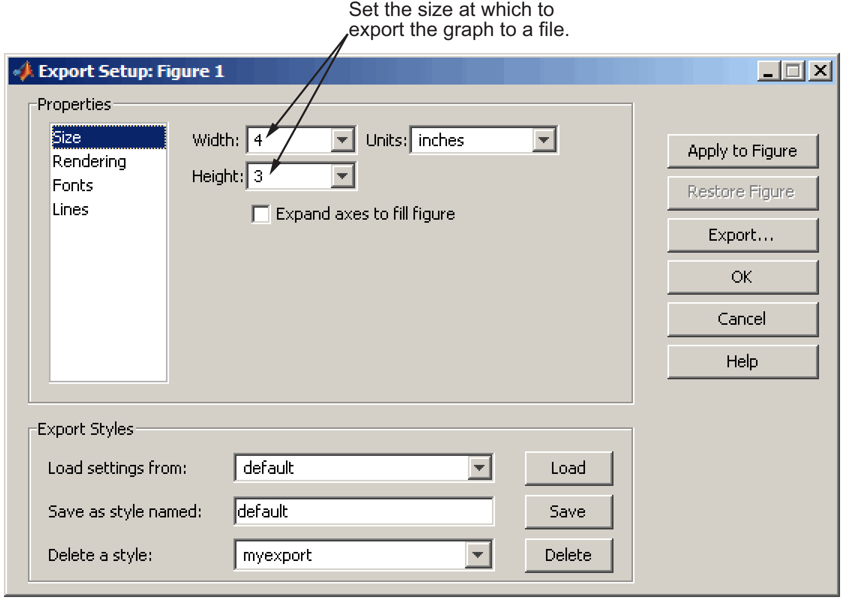
Exporting a graph is the process of creating a standard graphics file format of the graph (such as EPS or TIFF), which you can then import into other applications like word processors, drawing packages, etc.

This example exports the graph as an EPS file with the following requirements:

- The size of the picture when imported into the word processor document should be 4 inches wide and 3 inches high.
- All the text in the figure should have a size of 8 points.

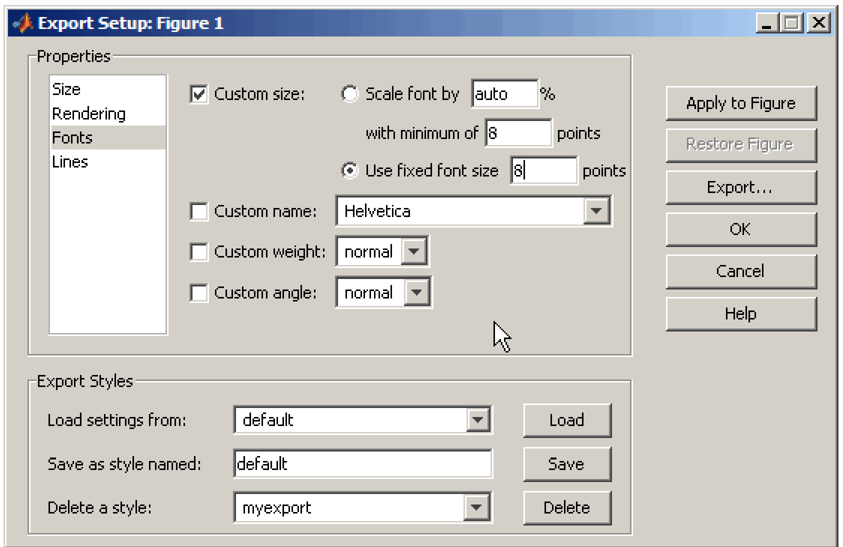
Specifying the Size of the Graph

To set the size, use the Export Setup dialog box (select **Export Setup** from the figure **File** menu). Then select `4` from the **Width** list and `3` from the **Height** list.



Specifying the Font Size

To set the font size of all the text in the graph, select `Fonts` in the Export Setup dialog box **Properties** selector. Then click **Use fixed font size** and enter `8` in the text box.



When you have finished specifying settings for exporting the figure, click the **Apply to Figure** button. The figure now displays the effect of settings you just made. If you do not apply the settings, the exported file will not display them.

Selecting the File Format

After you finish setting options for the exported graph, click the **Export** button. A standard Save As dialog box opens that enables you to specify a name for the file as well as select the type of file format you want to use.

The **Save as type** drop-down menu lists a number of other options for file formats. For this example, select `EPS (*.eps)` from the **Save as type** menu.

You can import the saved file into any application that supports EPS files.

You can also use the `print` command to print figures on your local printer or to export graphs to standard file types.

For More Information See the `print` command reference page and "Printing and Exporting" in the MATLAB Graphics documentation or select **Printing and Exporting** from the figure **Help** menu.

Using Basic Plotting Functions

In this section...

"Creating a Plot" on page 3-56
"Plotting Multiple Data Sets in One Graph" on page 3-57
"Specifying Line Styles and Colors" on page 3-58
"Plotting Lines and Markers" on page 3-59
"Graphing Imaginary and Complex Data" on page 3-61
"Adding Plots to an Existing Graph" on page 3-62
"Figure Windows" on page 3-63
"Displaying Multiple Plots in One Figure" on page 3-64
"Controlling the Axes" on page 3-66
"Adding Axis Labels and Titles" on page 3-67
"Saving Figures" on page 3-68

Creating a Plot

The plot function has different forms, depending on the input arguments. If y is a vector, plot(y) produces a piecewise linear graph of the elements of y versus the index of the elements of y. If you specify two vectors as arguments, plot(x,y) produces a graph of y versus x.

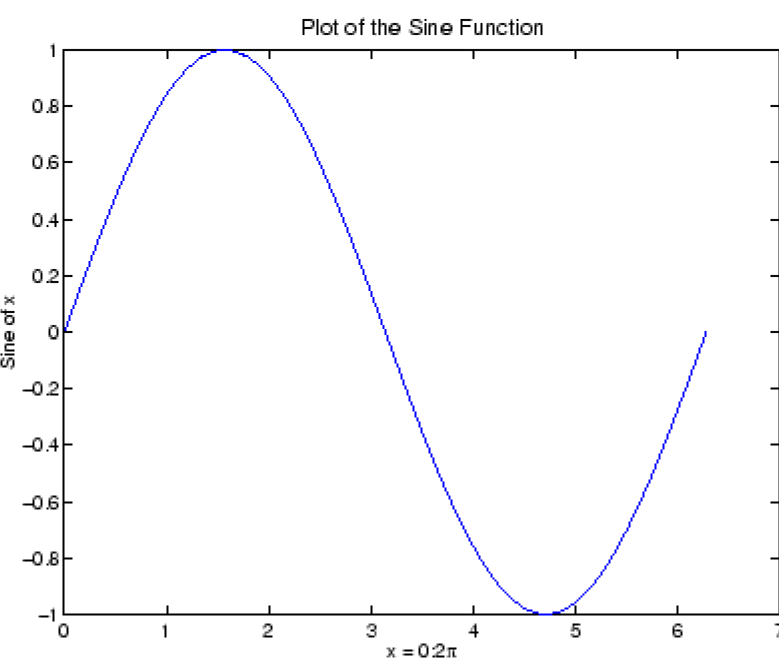
For example, these statements use the colon operator to create a vector of x values ranging from 0 to 2π, compute the sine of these values, and plot the result:

```
x = 0:pi/100:2*pi;
y = sin(x);
plot(x,y)
```

Now label the axes and add a title. The characters \pi create the symbol π. See "text strings" in the MATLAB Reference documentation for more symbols:

```
xlabel('x = 0:2\pi')
ylabel('Sine of x')
```

```
title('Plot of the Sine Function','FontSize',12)
```



Plotting Multiple Data Sets in One Graph

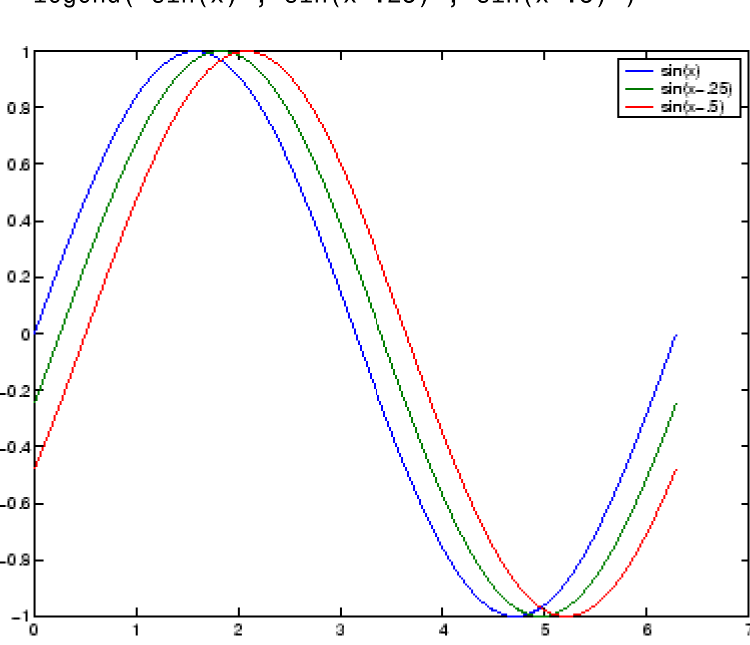
Multiple x-y pair arguments create multiple graphs with a single call to plot. automatically cycle through a predefined (but customizable) list of colors to allow discrimination among sets of data. See the axes ColorOrder and LineStyleOrder properties.

For example, these statements plot three related functions of x, with each curve in a separate distinguishing color:

```
x = 0:pi/100:2*pi;
y = sin(x);
y2 = sin(x-.25);
y3 = sin(x-.5);
plot(x,y,x,y2,x,y3)
```

The legend command provides an easy way to identify the individual plots:

```
legend('sin(x)','sin(x-.25)','sin(x-.5)')
```



For More Information See "Defining the Color of Lines for Plotting" in the MATLAB Graphics documentation.

Specifying Line Styles and Colors

It is possible to specify color, line styles, and markers (such as plus signs or circles) when you plot your data using the `plot` command:

```
plot(x,y,'color_style_marker')
```

`color_style_marker` is a string containing from one to four characters (enclosed in single quotation marks) constructed from a color, a line style, and a marker type. The strings are composed of combinations of the following elements:

Type	Values	Meanings
Color	`'c'`	cyan
	`'m'`	magenta
	`'y'`	yellow
	`'r'`	red
	`'g'`	green
	`'b'`	blue
	`'w'`	white
	`'k'`	black
Line style	`'-'`	solid
	`'--'`	dashed
	`':'`	dotted
	`'.-'`	dash-dot
	no character	no line
Marker type	`'+'`	plus mark
	`'o'`	unfilled circle
	`'*'`	asterisk
	`'x'`	letter x
	`'s'`	filled square
	`'d'`	filled diamond
	`'^'`	filled upward triangle
	`'v'`	filled downward triangle
	`'>'`	filled right-pointing triangle
	`'<'`	filled left-pointing triangle
	`'p'`	filled pentagram
	`'h'`	filled hexagram
	no character or `none`	no marker

You can also edit color, line style, and markers interactively. See “Editing Plots” on page 3-23 for more information.

Plotting Lines and Markers

If you specify a marker type but not a line style, only the marker is drawn. For example,

```
plot(x,y,'ks')
```

plots black squares at each data point, but does not connect the markers with a line.

The statement

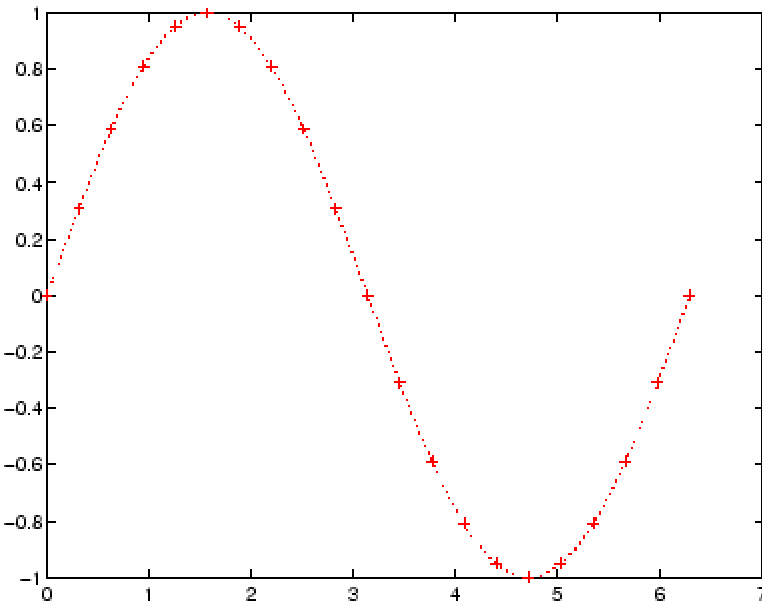
```
plot(x,y,'r:+')
```

plots a red-dotted line and places plus sign markers at each data point.

Placing Markers at Every Tenth Data Point

You might want to use fewer data points to plot the markers than you use to plot the lines. This example plots the data twice using a different number of points for the dotted line and marker plots:

```
x1 = 0:pi/100:2*pi;
x2 = 0:pi/10:2*pi;
plot(x1,sin(x1),'r:',x2,sin(x2),'r+')
```



Graphing Imaginary and Complex Data

When the arguments to `plot` are complex, the imaginary part is ignored *except* when you pass `plot` a single complex argument. For this special case, the command is a shortcut for a graph of the real part versus the imaginary part. Therefore,

```
plot(Z)
```

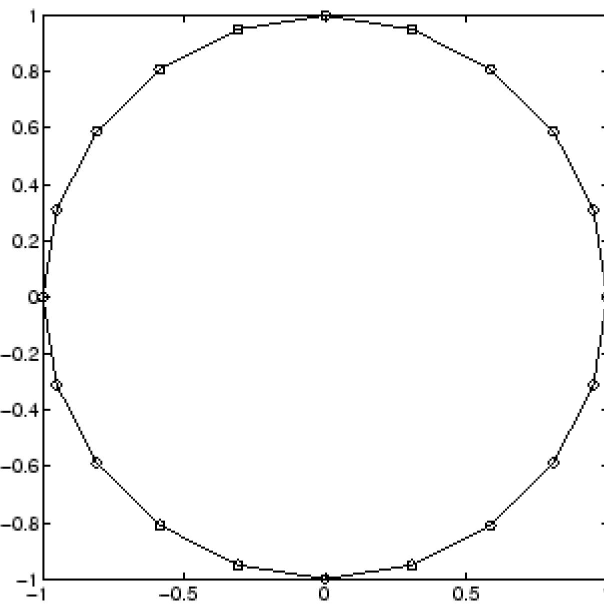
where `Z` is a complex vector or matrix, is equivalent to

```
plot(real(Z),imag(Z))
```

For example,

```
t = 0:pi/10:2*pi;
plot(exp(i*t),'-o')
axis equal
```

draws a 20-sided polygon with little circles at the vertices. The `axis equal` command makes the individual tick-mark increments on the *x*- and *y*-axes the same length, which makes this plot more circular in appearance.



Adding Plots to an Existing Graph

The MATLAB `hold` command enables you to add plots to an existing graph. When you type

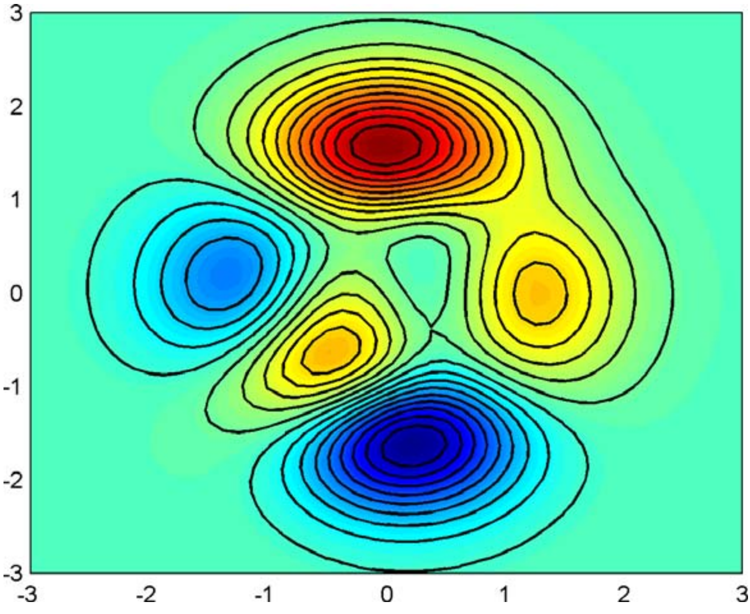
```
hold on
```

Now MATLAB does not replace the existing graph when you issue another plotting command; it adds the new data to the current graph, rescaling the axes if necessary.

For example, these statements first create a contour plot of the `peaks` function, then superimpose a pseudocolor plot of the same function:

```
[x,y,z] = peaks;
pcolor(x,y,z)
shading interp
hold on
contour(x,y,z,20,'k')
hold off
```

The `hold on` command combines the `pcolor` plot with the `contour` plot in one figure.



For More Information See "Creating Specialized Plots" in the MATLAB Graphics documentation for details about a variety of graph types.

Figure Windows

Graphing functions automatically open a new figure window if there are no figure windows already on the screen. If a figure window exists, it is used for graphics output. If there are multiple figure windows open, the one that is designated the "current figure" (the last figure used or clicked in) is used. See documentation for the `gcf` function for more information.

To make an existing figure window the current figure, you can click the mouse while the pointer is in that window or you can type

```
figure(n)
```

where `n` is the number in the figure title bar. The results of subsequent graphics commands are displayed in this window.

To open a new figure window and make it the current figure, type

```
figure
```

Clearing the Figure for a New Plot

When a figure already exists, most plotting commands clear the axes and use this figure to create the new plot. However, these commands do not reset figure properties, such as the background color or the colormap. If you have set any figure properties in the previous plot, you might want to use the `clf` command with the `reset` option,

```
clf reset
```

before creating your new plot to restore the figure's properties to their defaults.

For More Information See "Figure Properties" and "Graphics Windows — the Figure" in the MATLAB Graphics documentation for details about figures.

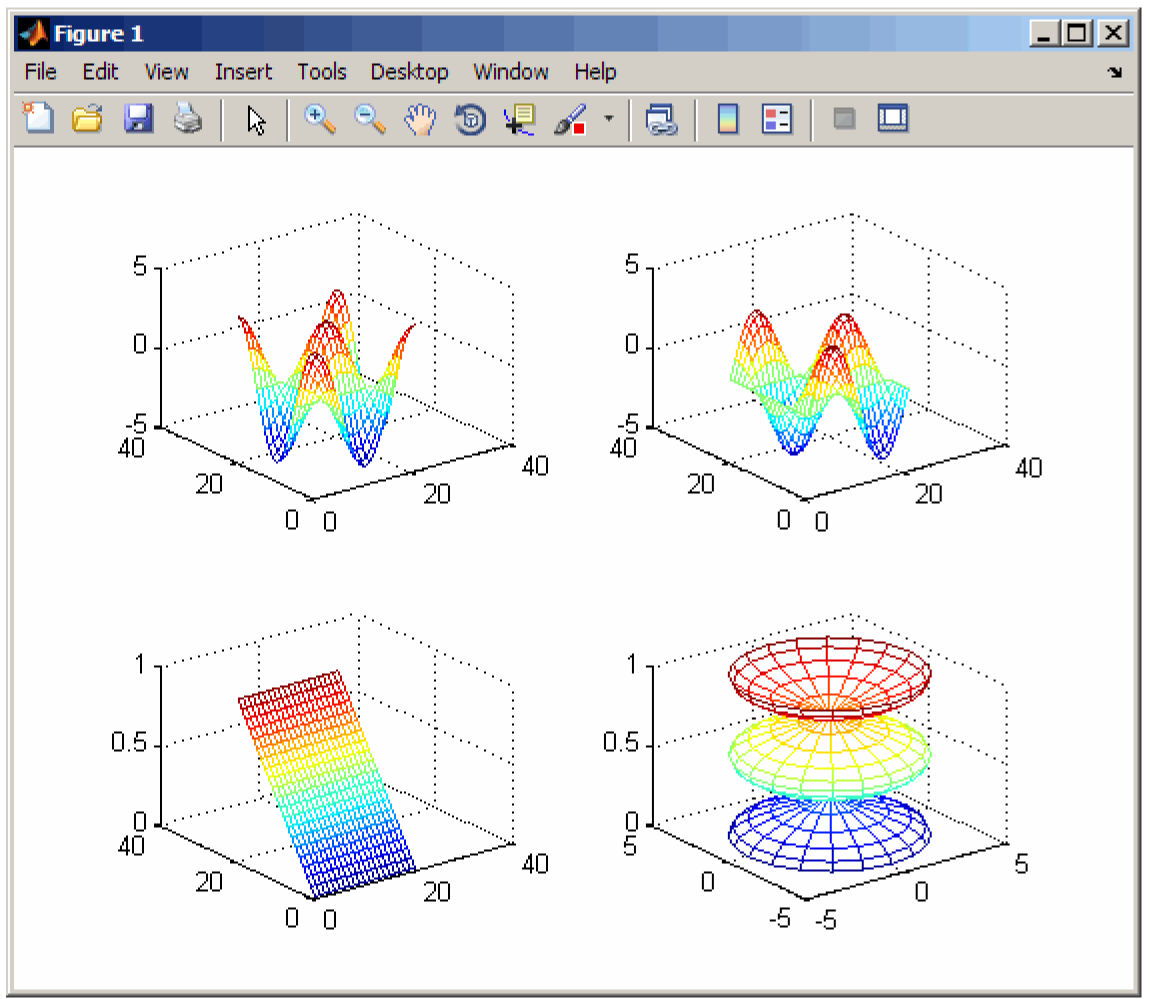
Displaying Multiple Plots in One Figure

The `subplot` command enables you to display multiple plots in the same window or print them on the same piece of paper. Typing

```
subplot(m,n,p)
```

partitions the figure window into an `m`-by-`n` matrix of small subplots and selects the `p`th subplot for the current plot. The plots are numbered along the first row of the figure window, then the second row, and so on. For example, these statements plot data in four different subregions of the figure window:

```
t = 0:pi/10:2*pi;
[X,Y,Z] = cylinder(4*cos(t));
subplot(2,2,1); mesh(X)
subplot(2,2,2); mesh(Y)
subplot(2,2,3); mesh(Z)
subplot(2,2,4); mesh(X,Y,Z)
```



You can add subplots to GUIs as well as to figures. For details about creating subplots in a GUIDE-generated GUI, see "Creating Subplots" in the MATLAB Creating Graphical User Interfaces documentation.

Controlling the Axes

The `axis` command provides a number of options for setting the scaling, orientation, and aspect ratio of graphs. You can also set these options interactively. See "Editing Plots" on page 3-23 for more information.

Setting Axis Limits

By default, MATLAB finds the maxima and minima of the data and chooses the axis limits to span this range. The `axis` command enables you to specify your own limits:

```
axis([xmin xmax ymin ymax])
```

or for three-dimensional graphs,

```
axis([xmin xmax ymin ymax zmin zmax])
```

Use the command

```
axis auto
```

to enable automatic limit selection again.

Setting the Axis Aspect Ratio

The `axis` command also enables you to specify a number of predefined modes. For example,

```
axis square
```

makes the x-axis and y-axis the same length.

```
axis equal
```

makes the individual tick mark increments on the x-axes and y-axes the same length. This means

```
plot(exp(i*[0:pi/10:2*pi]))
```

followed by either `axis square` or `axis equal` turns the oval into a proper circle:

```
axis auto normal
```

returns the axis scaling to its default automatic mode.

Setting Axis Visibility

You can use the axis command to make the axis visible or invisible.

```
axis on
```

makes the axes visible. This is the default.

```
axis off
```

makes the axes invisible.

Setting Grid Lines

The grid command toggles grid lines on and off. The statement

```
grid on
```

turns the grid lines on, and

```
grid off
```

turns them back off again.

For More Information See the axis and axes reference pages and "Axes Properties" in the MATLAB Graphics documentation.

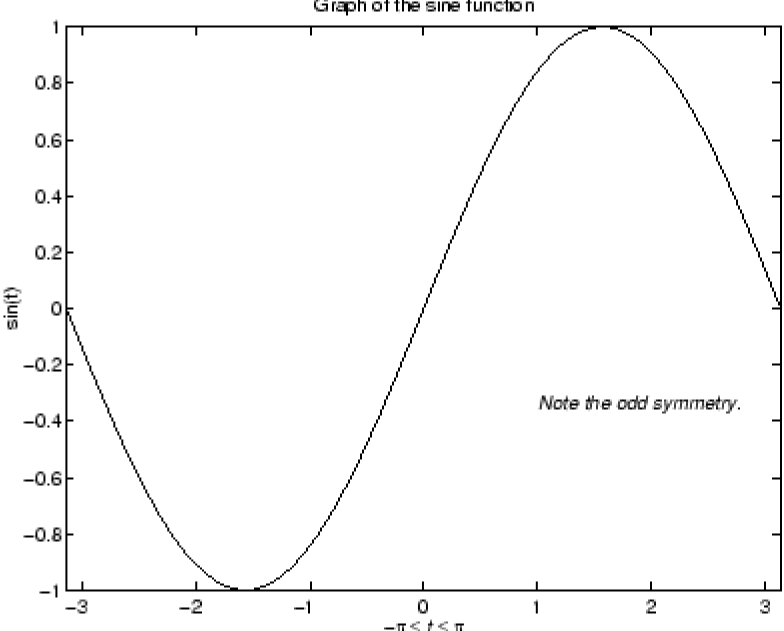
Adding Axis Labels and Titles

The xlabel, ylabel, and zlabel commands add *x*-, *y*-, and *z*-axis labels. The title command adds a title at the top of the figure and the text function inserts text anywhere in the figure.

You can produce mathematical symbols using LaTeX notation in the text string, as the following example illustrates:

```
t = -pi:pi/100:pi;
y = sin(t);
plot(t,y)
```

```
axis([-pi pi -1 1])
xlabel('-\pi \leq {\itt} \leq \pi')
ylabel('sin(t)')
title('Graph of the sine function')
text(1,-1/3,'{\itNote the odd symmetry.}')
```



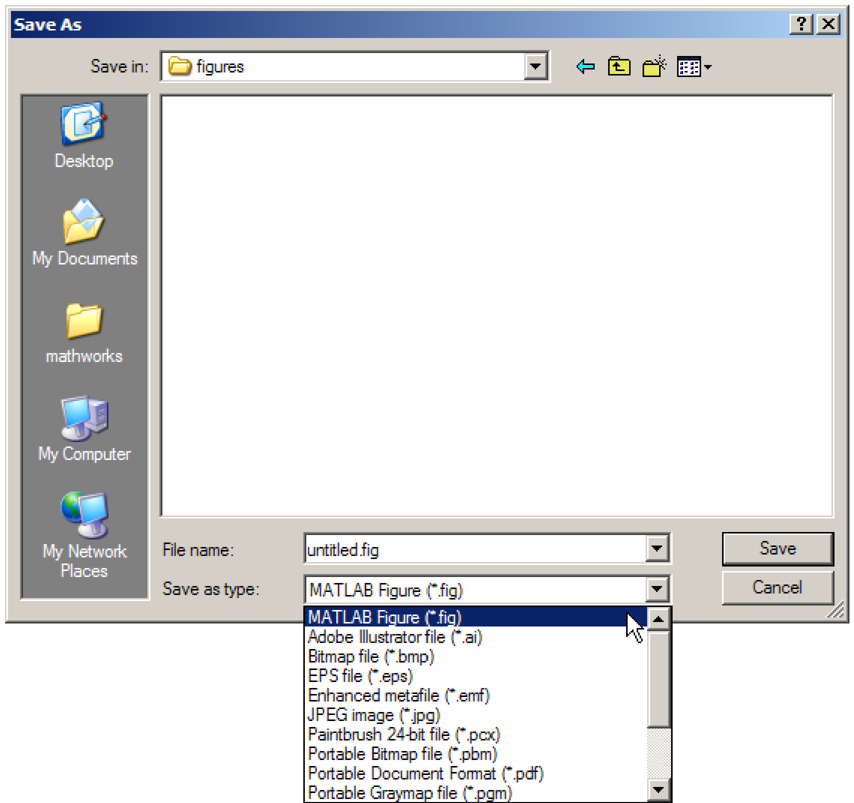
You can also set these options interactively. See “Editing Plots” on page 3-23 for more information.

Note that the location of the text string is defined in axes units (i.e., the same units as the data). See the `annotation` function for a way to place text in normalized figure units.

Saving Figures

Save a figure by selecting **Save** from the **File** menu. This writes the figure to a file, including data within it, its menus and other uicontrols it has, and all annotations (i.e., the entire window). If you have not saved the figure before,

the **Save As** dialog displays. It provides you with options to save the figure as a FIG-file or export it to a graphics format, as the following figure shows.



If you already have saved it, using **Save** again saves the figure "silently," without displaying the **Save As** dialog.

To save a figure using a standard graphics format for use with other applications, such as TIFF or JPG, select **Save As** (or **Export Setup**, if you want additional control) from the **File** menu.

Note Whenever you specify a format for saving a figure, that file format is used again the next time you save that figure or a new one. If you do not want to save in the previously-used format, use **Save As** and be sure to set the **Save as type** drop-down menu to the kind of file you want to write.

You can also save from the command line—use the `saveas` command, including any options to save the figure in a different format. The more restricted `hgexport` command, which saves figures to either bitmap or metafile files, depending on the rendering method in effect, is also available.

See "Exporting the Graph" on page 3-52 for an example.

Saving Workspace Data

You can save the variables in your workspace by selecting **Save Workspace As** from the figure **File** menu. You can reload saved data using the **Import Data** item in the figure **File** menu. MATLAB supports a variety of data file formats, including MATLAB data files, which have a `.mat` extension.

Generating M-Code to Recreate a Figure

You can generate MATLAB code that recreates a figure and the graph it contains by selecting **Generate M-File** from the figure **File** menu. This option is particularly useful if you have developed a graph using plotting tools and want to create a similar graph using the same or different data.

Saving Figures That Are Compatible with the Previous MATLAB Software Version

Create backward-compatible FIG-files by following these two steps:

1. Ensure that any plotting functions used to create the contents of the figure are called with the `'v6'` argument, where applicable.

2. Use the `'-v6'` option with the `hgsave` command.

Note The `v6` option enables users of Version 7.x of MATLAB to create FIG-files that previous versions can open. It is obsolete and will be removed in a future version of MATLAB. For more information, see "Plot Objects and Backward Compatibility" in the MATLAB Graphics documentation.

Creating Mesh and Surface Plots

In this section...
"About Mesh and Surface Plots" on page 3-72
"Visualizing Functions of Two Variables" on page 3-72

About Mesh and Surface Plots

You define a surface by the *z*-coordinates of points above a grid in the *x*-*y* plane, using straight lines to connect adjacent points. The `mesh` and `surf` plotting functions display surfaces in three dimensions. `mesh` produces wireframe surfaces that color only the lines connecting the defining points. `surf` displays both the connecting lines and the faces of the surface in color.

The figure colormap and figure properties determine how the surface is colored.

Visualizing Functions of Two Variables

To display a function of two variables, $z = f(x,y)$,

1. Generate `X` and `Y` matrices consisting of repeated rows and columns, respectively, over the domain of the function.

2. Use `X` and `Y` to evaluate and graph the function.

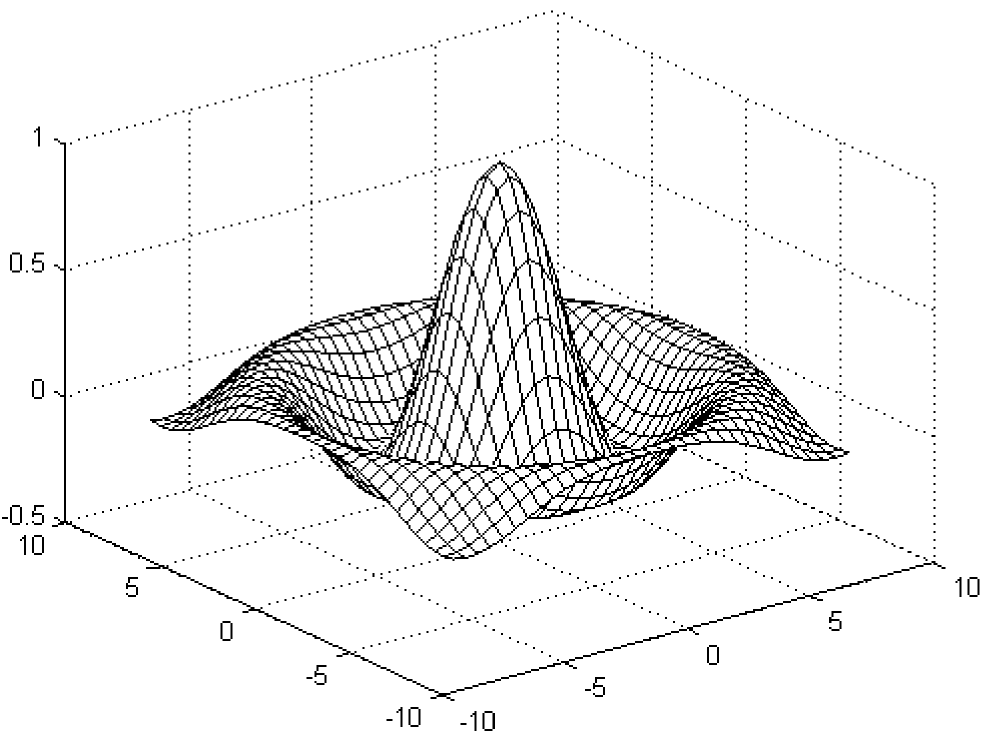
The `meshgrid` function transforms the domain specified by a single vector or two vectors `x` and `y` into matrices `X` and `Y` for use in evaluating functions of two variables. The rows of `X` are copies of the vector `x` and the columns of `Y` are copies of the vector `y`.

Example — Graphing the sinc Function

This example evaluates and graphs the two-dimensional `sinc` function, $\sin(r)/r$, between the *x* and *y* directions. `R` is the distance from the origin, which is at the center of the matrix. Adding `eps` (a MATLAB command that returns a small floating-point number) avoids the indeterminate 0/0 at the origin:

```
[X,Y] = meshgrid(-8:.5:8);
```

```
R = sqrt(X.^2 + Y.^2) + eps;
Z = sin(R)./R;
mesh(X,Y,Z,'EdgeColor','black')
```



By default, the current colormap is used to color the mesh. However, this example uses a single-colored mesh by specifying the `EdgeColor` surface property. See the `surface` reference page for a list of all surface properties.

You can create a mesh with see-through faces by disabling hidden line removal:

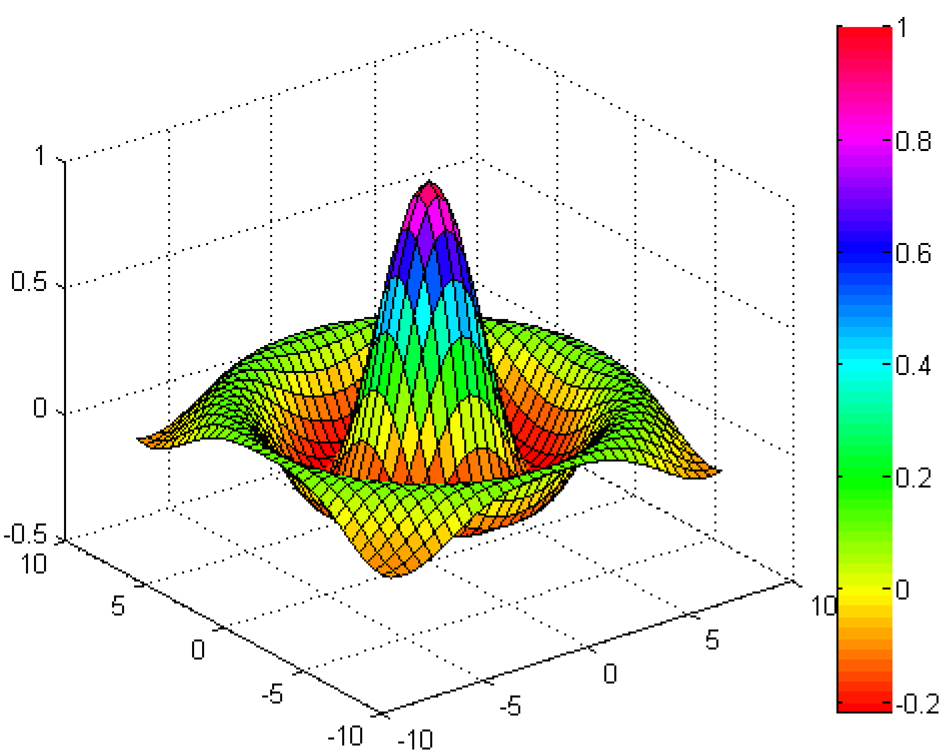
```
hidden off
```

See the `hidden` reference page for more information on this option.

Example — Colored Surface Plots

A surface plot is similar to a mesh plot except that the rectangular faces of the surface are colored. The color of each face is determined by the values of Z and the colormap (a colormap is an ordered list of colors). These statements graph the sinc function as a surface plot, specify a colormap, and add a color bar to show the mapping of data to color:

```
surf(X,Y,Z)
colormap hsv
colorbar
```



See the colormap reference page for information on colormaps.

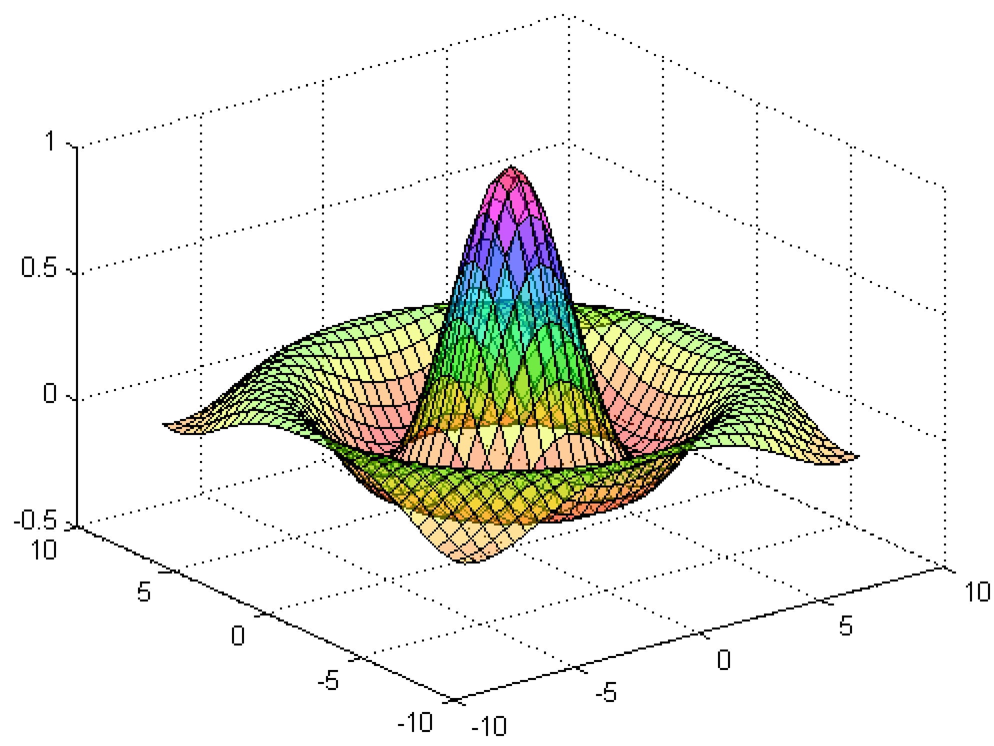
For More Information See "Creating 3-D Graphs" in the MATLAB 3-D Visualization documentation for more information on surface plots.

Making Surfaces Transparent

You can make the faces of a surface transparent to a varying degree. Transparency (referred to as the alpha value) can be specified for the whole object or can be based on an `alphamap`, which behaves similarly to colormaps. For example,

```
surf(X,Y,Z)
colormap hsv
alpha(.4)
```

produces a surface with a face alpha value of 0.4. Alpha values range from 0 (completely transparent) to 1 (not transparent).



For More Information See "Manipulating Transparency" in the MATLAB 3-D Visualization documentation for details about using this feature.

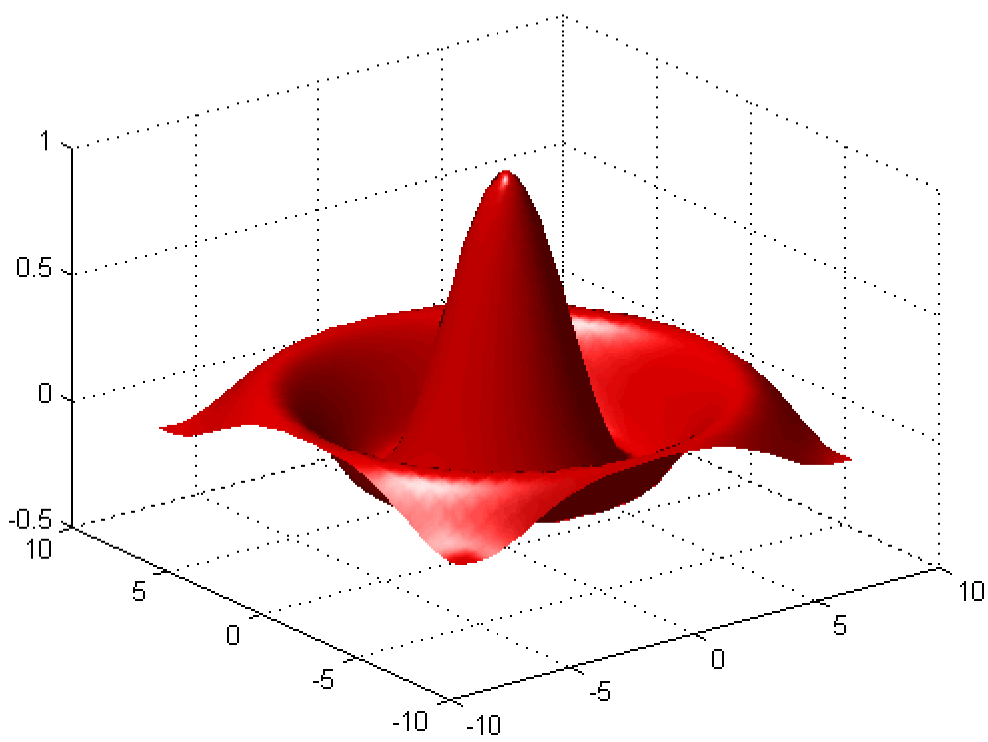
Illuminating Surface Plots with Lights

Lighting is the technique of illuminating an object with a directional light source. In certain cases, this technique can make subtle differences in surface shape easier to see. Lighting can also be used to add realism to three-dimensional graphs.

This example uses the same surface as the previous examples, but colors it red and removes the mesh lines. A light object is then added to the left of the

"camera" (the camera is the location in space from where you are viewing the surface):

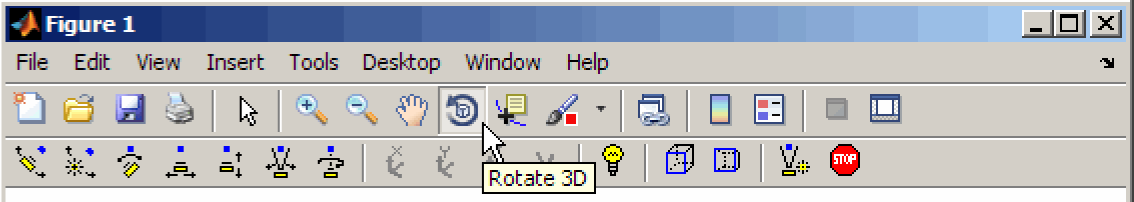
```
surf(X,Y,Z,'FaceColor','red','EdgeColor','none')
camlight left; lighting phong
```



Manipulating the Surface

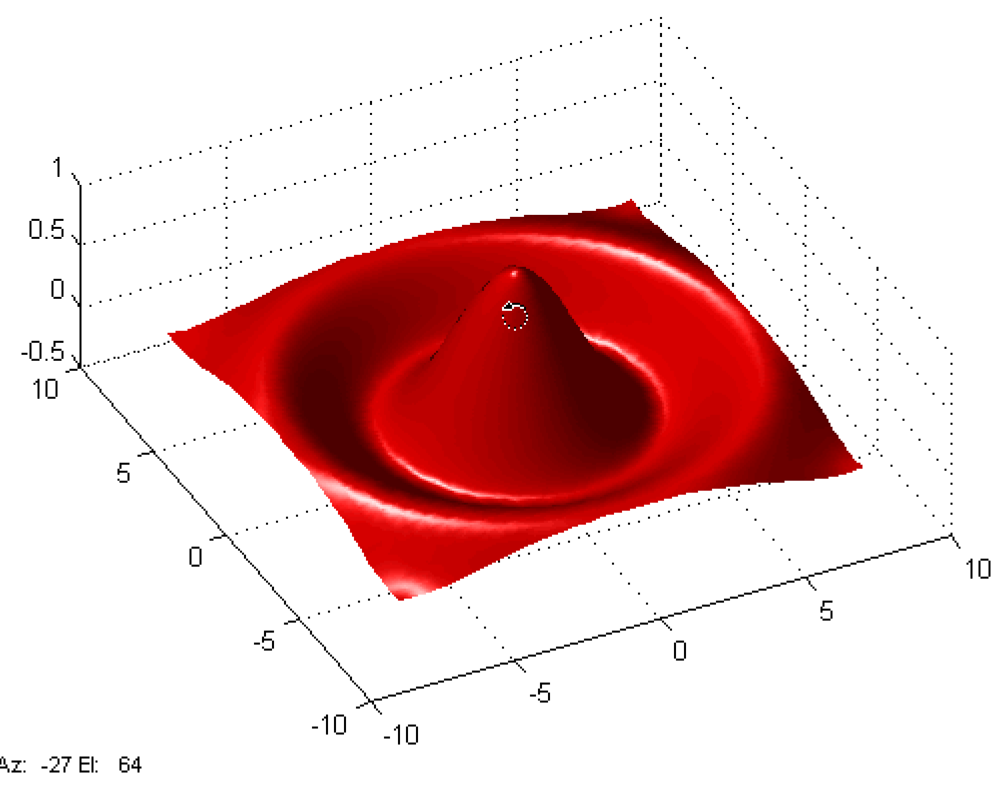
The figure toolbar and the camera toolbar provide ways to explore 3-D graphics interactively. Display the camera toolbar by selecting **Camera Toolbar** from the figure **View** menu.

The following picture shows both toolbars with the **Rotate 3D** tool selected.



These tools enable you to move the camera around the surface object, zoom, add lighting, and perform other viewing operations without issuing commands.

The following picture shows the surface viewed by orbiting the camera toward the bottom using **Rotate 3D**. You can see the tools's cursor icon on the surface where as you drag to rotate the view. As you drag, the viewing altitude and elevation read out in the lower left corner of the axes, as the picture shows.



For More Information See “Lighting as a Visualization Tool” and “View Control with the Camera Toolbar” in the MATLAB 3-D Visualization documentation for details about these techniques.

Plotting Image Data

In this section...

"About Plotting Image Data" on page 3-80

"Reading and Writing Images" on page 3-81

About Plotting Image Data

Two-dimensional arrays can be displayed as *images*, where the array elements determine brightness or color of the images. For example, the statements

```
load durer
whos
Name          Size         Bytes  Class

  X           648x509      2638656  double array
  caption     2x28             112  char array
  map         128x3           3072  double array
```

load the file `durer.mat`, adding three variables to the workspace. The matrix `X` is a 648-by-509 matrix and `map` is a 128-by-3 matrix that is the colormap for this image.

MAT-files, such as `durer.mat`, are binary files that can be created on one platform and later read by the MATLAB software on a different platform.

The elements of `X` are integers between 1 and 128, which serve as indices into the colormap, `map`. Then

```
image(X)
colormap(map)
axis image
```

reproduces Albrecht Dürer's etching shown in "Matrices and Magic Squares" on page 2-2. A high-resolution scan of the magic square in the upper-right corner is available in another file. Type

```
load detail
```

and then use the up arrow key on your keyboard to reexecute the `image`, `colormap`, and `axis` commands. The statement

```
colormap(hot)
```

adds some 21st century colorization to the 16th century etching. The function `hot` generates a colormap containing shades of reds, oranges, and yellows. Typically, a given image matrix has a specific colormap associated with it. See the `colormap` reference page for a list of other predefined colormaps.

Reading and Writing Images

You can read standard image files (TIFF, JPEG, BMP, etc using the `imread` function. The type of data returned by `imread` depends on the type of image you are reading.

You can write MATLAB data to a variety of standard image formats using the `imwrite` function. See the MATLAB reference pages for these functions for more information and examples.

For More Information See “Displaying Bit-Mapped Images” in the MATLAB Graphics documentation for details about MATLAB image processing capabilities.

Printing Graphics

In this section...

"Overview of Printing" on page 3-82
"Printing from the File Menu" on page 3-82
"Exporting the Figure to a Graphics File" on page 3-83
"Using the Print Command" on page 3-83

Overview of Printing

You can print a MATLAB figure directly on a printer connected to your computer or you can export the figure to one of the standard graphics file formats that MATLAB supports. There are two ways to print and export figures:

- Use the **Print**, **Print Preview**, or **Export Setup** GUI options under the **File** menu; see "Preparing Graphs for Presentation" on page 3-43 for an example.
- Use the `print` command to print or export the figure from the command line.

The `print` command provides greater control over drivers and file formats. The Print Preview dialog box gives you greater control over figure size, proportions, placement, and page headers. You can sometimes notice differences in output as printed from a GUI and as printed from the command line.

Printing from the File Menu

There are two menu options under the **File** menu that pertain to printing:

- The **Print Preview** option displays a dialog box that lets you lay out and style figures for printing while previewing the output page, and from which you can print the figure. It includes options that formerly were part of the Page Setup dialog box.

- The **Print** option displays a dialog box that lets you choose a printer, select standard printing options, and print the figure.

Use **Print Preview** to determine whether the printed output is what you want. Click the Print Preview dialog box **Help** button to display information on how to set up the page.

See "Printing the Graph" on page 3-48 for an example of printing from the Print Preview dialog. For details on printing from GUIs and from the Command Window, see "Printing and Exporting" in the MATLAB Graphics documentation.

Exporting the Figure to a Graphics File

The **Export Setup** option in the **File** menu opens a GUI that enables you to set graphic characteristics, such as text size, font, and style, for figures you save as graphics files. The Export Setup GUI lets you define and apply templates to customize and standardize output. After setup, you can export the figure to a number of standard graphics file formats such as EPS, PNG, and TIFF.

See "Exporting the Graph" on page 3-52 for an example of exporting a figure to a graphics file.

Using the Print Command

The `print` command provides more flexibility in the type of output sent to the printer and allows you to control printing from M-files. The result can be sent directly to your default printer or stored in a specified file. A wide variety of output formats, including TIFF, JPEG, and PostScript, is available.

For example, this statement saves the contents of the current figure window as color Encapsulated Level 2 PostScript in the file called `magicsquare.eps`. It also includes a TIFF preview, which enables most word processors to display the picture.

```
print -depsc2 -tiff magicsquare.eps
```

To save the same figure as a TIFF file with a resolution of 200 dpi, use the following command:

```
print -dtiff -r200 magicsquare.tiff
```

If you type `print` on the command line

```
print
```

the current figure prints on your default printer.

For More Information See the `print` reference page and "Printing and Exporting" in the MATLAB Graphics documentation for details about printing.

Understanding Handle Graphics Objects

In this section...

"Using the Handle" on page 3-85

"Graphics Objects" on page 3-86

"Setting Object Properties" on page 3-88

"Specifying the Axes or Figure" on page 3-91

"Finding the Handles of Existing Objects" on page 3-92

Handle Graphics objects are MATLAB objects that implement graphing and visualization functions. Each object created has a fixed set of properties. You can use these properties to control the behavior and appearance of your graph.

When you call a MATLAB plotting function, it creates the graph using various graphics objects, such as a figure window, axes, lines, text, and so on. You can query the value of each property and set the values of most of them.

For example, the following statement creates a figure with a white background color and without displaying the figure toolbar:

```
figure('Color','white','Toolbar','none')
```

Using the Handle

Whenever MATLAB creates a graphics object, it assigns an identifier (called a *handle*) to the object. You can use this handle to access the object's properties with the `set` and `get` functions. For example, the following statements create a graph and return a handle to a lineseries object in `h`:

```
x = 1:10;
y = x.^3;
h = plot(x,y);
```

You can use the handle `h` to set the properties of the lineseries object. For example, you can set its `Color` property:

```
set(h,'Color','red')
```

You can also specify properties when you call the plotting function:

```
h = plot(x,y,'Color','red');
```

When you query the lineseries properties,

```
get(h,'LineWidth')
```

You obtain the answer:

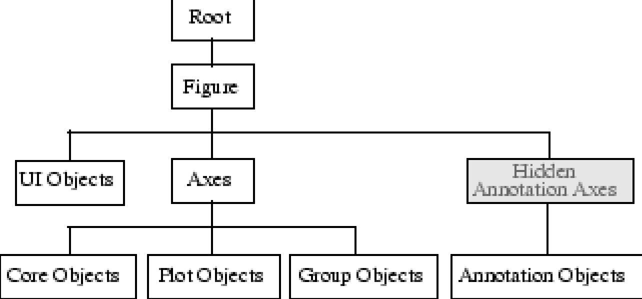
```
ans =
 0.5000
```

Use the handle to see what properties a particular object contains:

```
get(h)
```

Graphics Objects

Graphics objects are the basic elements used to display graphs and user interface components. These objects are organized into a hierarchy, as shown by the following diagram.



Key Graphics Objects

When you call a function to create a MATLAB graph, a hierarchy of graphics objects results. For example, calling the `plot` function creates the following graphics objects:

- Lineseries plot objects — Represent the data passed to the `plot` function.
- Axes — Provide a frame of reference and scaling for the plotted lineseries.
- Text — Label the axes tick marks and are used for titles and annotations.

- Figures — Are the windows that contain axes toolbars, menus, etc.

Different types of graphs use different objects to represent data; however, all data objects are contained in axes and all objects (except root) are contained in figures.

The root is an abstract object that primarily stores information about your computer or MATLAB state. You cannot create an instance of the root object.

For More Information See "Handle Graphics Objects" in the MATLAB Graphics documentation for details about graphics objects.

User interface objects are used to create graphical user interfaces (GUIs). These objects include components like push buttons, editable text boxes, and list boxes.

For More Information See Chapter 6, "Creating Graphical User Interfaces" for details about user interface objects.

Creating Objects

Plotting functions (like `plot` and `surf`) call the appropriate low-level function to draw their respective graph. For information about an object's properties, you can use the Handle Graphics Property Browser in the MATLAB online Graphics documentation.

Functions for Working with Objects

This table lists functions commonly used when working with objects.

Function	Purpose
`allchild`	Find all children of specified objects.
`ancestor`	Find ancestor of graphics object.
`copyobj`	Copy graphics object.

Function	Purpose
`delete`	Delete an object.
`findall`	Find all graphics objects (including hidden handles).
`findobj`	Find the handles of objects having specified property values.
`gca`	Return the handle of the current axes.
`gcf`	Return the handle of the current figure.
`gco`	Return the handle of the current object.
`get`	Query the values of an object's properties.
`ishandle`	True if the value is a valid object handle.
`set`	Set the values of an object's properties.

Setting Object Properties

All object properties have default values. However, you might find it useful to change the settings of some properties to customize your graph. There are two ways to set object properties:

- Specify values for properties when you create the object.
- Set the property value on an object that already exists.

Setting Properties from Plotting Commands

You can specify object property value pairs as arguments to many plotting functions, such as `plot`, `mesh`, and `surf`.

For example, plotting commands that create lineseries or surfaceplot objects enable you to specify property name/property value pairs as arguments. The command

```
surf(x,y,z,'FaceColor','interp',...
   'FaceLighting','gouraud')
```

plots the data in the variables x, y, and z using a surfaceplot object with interpolated face color and employing the Gouraud face light technique. You can set any of the object's properties this way.

Setting Properties of Existing Objects

To modify the property values of existing objects, you can use the set command or the Property Editor. This section describes how to use the set command. See "Using the Property Editor" on page 3-24 for more information.

Most plotting functions return the handles of the objects that they create so you can modify the objects using the set command. For example, these statements plot a 5-by-5 matrix (creating five lineseries, one per column), and then set the Marker property to a square and the MarkerFaceColor property to green:

```
h = plot(magic(5));
set(h,'Marker','s','MarkerFaceColor','g')
```

In this case, h is a vector containing five handles, one for each of the five lineseries in the graph. The set statement sets the Marker and MarkerFaceColor properties of all lineseries to the same values.

Setting Multiple Property Values

If you want to set the properties of each lineseries to a different value, you can use cell arrays to store all the data and pass it to the set command. For example, create a plot and save the lineseries handles:

```
h = plot(magic(5));
```

Suppose you want to add different markers to each lineseries and color the marker's face color the same color as the lineseries. You need to define two cell arrays—one containing the property names and the other containing the desired values of the properties.

The prop_name cell array contains two elements:

```
prop_name(1) = {'Marker'};
prop_name(2) = {'MarkerFaceColor'};
```

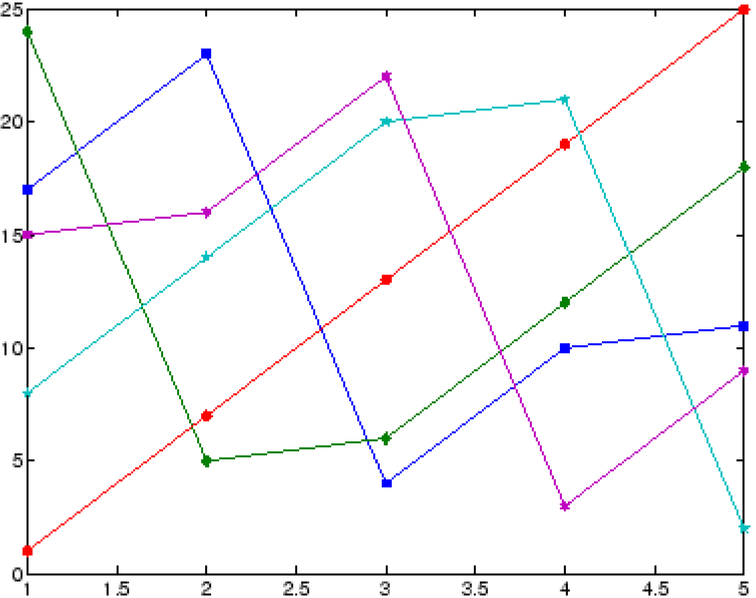
The `prop_values` cell array contains 10 values: five values for the `Marker` property and five values for the `MarkerFaceColor` property. Notice that `prop_values` is a two-dimensional cell array. The first dimension indicates which handle in `h` the values apply to and the second dimension indicates which property the value is assigned to:

```
prop_values(1,1) = {'s'};
prop_values(1,2) = {get(h(1),'Color')};
prop_values(2,1) = {'d'};
prop_values(2,2) = {get(h(2),'Color')};
prop_values(3,1) = {'o'};
prop_values(3,2) = {get(h(3),'Color')};
prop_values(4,1) = {'p'};
prop_values(4,2) = {get(h(4),'Color')};
prop_values(5,1) = {'h'};
prop_values(5,2) = {get(h(5),'Color')};
```

The `MarkerFaceColor` is always assigned the value of the corresponding line's color (obtained by getting the lineseries `Color` property with the `get` command).

After defining the cell arrays, call `set` to specify the new property values:

```
set(h,prop_name,prop_values)
```



Specifying the Axes or Figure

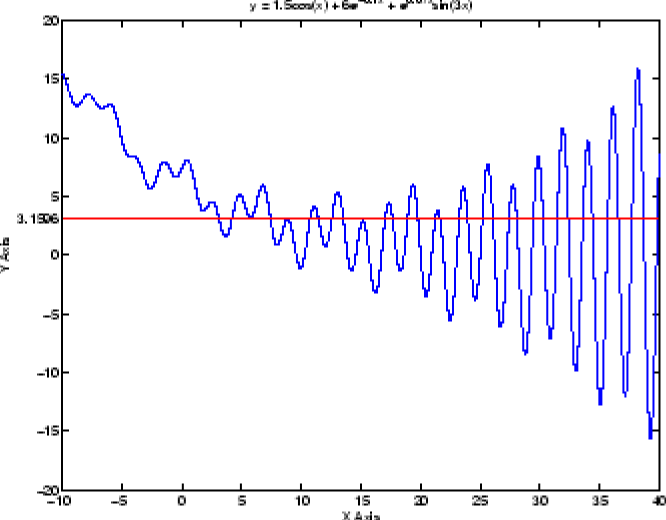
MATLAB always creates an axes or figure if one does not exist when you issue a plotting command. However, when you are creating a graphics M-file, it is good practice to explicitly create and specify the parent axes and figure, particularly if others will use your program. Specifying the parent prevents the following problems:

- Your M-file overwrites the graph in the current figure. A figure becomes the current figure whenever a user clicks it.
- The current figure might be in an unexpected state and not behave as your program expects.

The following example shows a simple M-file that plots a function and the mean of the function over the specified range:

```
function myfunc(x)
% x = -10:.005:40; Here's a value you can use for x
y = [1.5*cos(x) + 6*exp(-.1*x) + exp(.07*x).*sin(3*x)];
ym = mean(y);
```

```
hfig = figure('Name','Function and Mean',...
  'Pointer','fullcrosshair');
hax = axes('Parent',hfig);
plot(hax,x,y)
hold on
plot(hax,[min(x) max(x)],[ym ym],'Color','red')
hold off
ylab = get(hax,'YTick');
set(hax,'YTick',sort([ylab ym]))
title ('y = 1.5cos(x) + 6e^{-0.1x} + e^{0.07x}sin(3x)')
xlabel('X Axis'); ylabel('Y Axis')
```



Finding the Handles of Existing Objects

The `findobj` function enables you to obtain the handles of graphics objects by searching for objects with particular property values. With `findobj` you can specify the values of any combination of properties, which makes it easy to pick one object out of many. `findobj` also recognizes regular expressions (`regexp`).

For example, you might want to find the blue line with square marker having blue face color. You can also specify which figures or axes to search, if there

are more than one. The following four sections provide examples illustrating how to use `findobj`.

Finding All Objects of a Certain Type

Because all objects have a `Type` property that identifies the type of object, you can find the handles of all occurrences of a particular type of object. For example,

```
h = findobj('Type','patch');
```

finds the handles of all patch objects.

Finding Objects with a Particular Property

You can specify multiple properties to narrow the search. For example,

```
h = findobj('Type','line','Color','r','LineStyle',':');
```

finds the handles of all red dotted lines.

Limiting the Scope of the Search

You can specify the starting point in the object hierarchy by passing the handle of the starting figure or axes as the first argument. For example,

```
h = findobj(gca,'Type','text','String','\pi/2');
```

finds the string $\pi/2$ only within the current axes.

Using findobj as an Argument

Because `findobj` returns the handles it finds, you can use it in place of the handle argument. For example,

```
set(findobj('Type','line','Color','red'),'LineStyle',':')
```

finds all red lines and sets their line style to dotted.

Programming

If you have an active Internet Explorer® connection, you can watch the Writing a MATLAB Program video demo for an overview of the major functionality.

- "Flow Control" on page 4-2
- "Other Data Structures" on page 4-9
- "Scripts and Functions" on page 4-20
- "Object-Oriented Programming" on page 4-33

Flow Control

In this section...

"Conditional Control — if, else, switch" on page 4-2

"Loop Control — for, while, continue, break" on page 4-5

"Error Control — try, catch" on page 4-7

"Program Termination — return" on page 4-8

Conditional Control — if, else, switch

This section covers those MATLAB product functions that provide conditional program control.

if, else, and elseif

The `if` statement evaluates a logical expression and executes a group of statements when the expression is *true*. The optional `elseif` and `else` keywords provide for the execution of alternate groups of statements. An `end` keyword, which matches the `if`, terminates the last group of statements. The groups of statements are delineated by the four keywords—no braces or brackets are involved.

The MATLAB algorithm for generating a magic square of order n involves three different cases: when n is odd, when n is even but not divisible by 4, or when n is divisible by 4. This is described by

```
if rem(n,2) ~= 0
   M = odd_magic(n)
elseif rem(n,4) ~= 0
   M = single_even_magic(n)
else
   M = double_even_magic(n)
end
```

For most values of `n` in this example, the three cases are mutually exclusive. For values that are not mutually exclusive, such as `n=5`, the first *true* condition is executed.

It is important to understand how relational operators and `if` statements work with matrices. When you want to check for equality between two variables, you might use

```
if A == B, ...
```

This is valid MATLAB code, and does what you expect when `A` and `B` are scalars. But when `A` and `B` are matrices, `A == B` does not test *if* they are equal, it tests *where* they are equal; the result is another matrix of 0's and 1's showing element-by-element equality. (In fact, if `A` and `B` are not the same size, then `A == B` is an error.)

```
A = magic(4);     B = A;     B(1,1) = 0;

A == B
ans =
     0     1     1     1
     1     1     1     1
     1     1     1     1
     1     1     1     1
```

The proper way to check for equality between two variables is to use the `isequal` function:

```
if isequal(A, B), ...
```

`isequal` returns a *scalar* logical value of `1` (representing `true`) or `0` (`false`), instead of a matrix, as the expression to be evaluated by the `if` function. Using the `A` and `B` matrices from above, you get

```
isequal(A, B)
ans =
    0
```

Here is another example to emphasize this point. If `A` and `B` are scalars, the following program will never reach the "unexpected situation". But for most pairs of matrices, including our magic squares with interchanged columns, none of the matrix conditions `A > B`, `A < B`, or `A == B` is true for *all* elements and so the `else` clause is executed:

```
if A > B
   'greater'
```

```
elseif A < B
   'less'
elseif A == B
   'equal'
else
   error('Unexpected situation')
end
```

Several functions are helpful for reducing the results of matrix comparisons to scalar conditions for use with `if`, including

```
isequal
isempty
all
any
```

switch and case

The `switch` statement executes groups of statements based on the value of a variable or expression. The keywords `case` and `otherwise` delineate the groups. Only the first matching case is executed. There must always be an `end` to match the `switch`.

The logic of the magic squares algorithm can also be described by

```
switch (rem(n,4)==0) + (rem(n,2)==0)
   case 0
      M = odd_magic(n)
   case 1
      M = single_even_magic(n)
   case 2
      M = double_even_magic(n)
   otherwise
      error('This is impossible')
end
```

Note Unlike the C language `switch` statement, the MATLAB `switch` does not fall through. If the first `case` statement is `true`, the other `case` statements do not execute. So, `break` statements are not required.

Loop Control — for, while, continue, break

This section covers those MATLAB functions that provide control over program loops.

for

The `for` loop repeats a group of statements a fixed, predetermined number of times. A matching `end` delineates the statements:

```
for n = 3:32
   r(n) = rank(magic(n));
end
r
```

The semicolon terminating the inner statement suppresses repeated printing, and the `r` after the loop displays the final result.

It is a good idea to indent the loops for readability, especially when they are nested:

```
for i = 1:m
   for j = 1:n
      H(i,j) = 1/(i+j);
   end
end
```

while

The `while` loop repeats a group of statements an indefinite number of times under control of a logical condition. A matching `end` delineates the statements.

Here is a complete program, illustrating `while`, `if`, `else`, and `end`, that uses interval bisection to find a zero of a polynomial:

```
a = 0; fa = -Inf;
b = 3; fb = Inf;
while b-a > eps*b
   x = (a+b)/2;
   fx = x^3-2*x-5;
   if sign(fx) == sign(fa)
      a = x; fa = fx;
```

```
    else
       b = x; fb = fx;
    end
end
x
```

The result is a root of the polynomial $x^3 - 2x - 5$, namely

```
x =
   2.09455148154233
```

The cautions involving matrix comparisons that are discussed in the section on the `if` statement also apply to the `while` statement.

continue

The `continue` statement passes control to the next iteration of the `for` loop or `while` loop in which it appears, skipping any remaining statements in the body of the loop. The same holds true for `continue` statements in nested loops. That is, execution continues at the beginning of the loop in which the `continue` statement was encountered.

The example below shows a `continue` loop that counts the lines of code in the file `magic.m`, skipping all blank lines and comments. A `continue` statement is used to advance to the next line in `magic.m` without incrementing the count whenever a blank line or comment line is encountered:

```
fid = fopen('magic.m','r');
count = 0;
while ~feof(fid)
    line = fgetl(fid);
    if isempty(line) || strncmp(line,'%',1) || ~ischar(line)
        continue
    end
    count = count + 1;
end
fprintf('%d lines\n',count);
fclose(fid);
```

break

The `break` statement lets you exit early from a `for` loop or `while` loop. In nested loops, `break` exits from the innermost loop only.

Here is an improvement on the example from the previous section. Why is this use of `break` a good idea?

```
a = 0; fa = -Inf;
b = 3; fb = Inf;
while b-a > eps*b
   x = (a+b)/2;
   fx = x^3-2*x-5;
   if fx == 0
      break
   elseif sign(fx) == sign(fa)
      a = x; fa = fx;
   else
      b = x; fb = fx;
   end
end
x
```

Error Control — try, catch

This section covers those MATLAB functions that provide error handling control.

try

The general form of a `try-catch` statement sequence is

```
try
   statement
   ...
   statement
catch exceptObj
   statement
   ...
   statement
end
```

In this sequence, the statements in the `try` block (that part of the try-catch that follows the word `try` statement, and precedes `catch`) between `try` and `catch` execute just like any other program code. If an error occurs within the `try` section The statements between `catch` and `end` are then executed. Examine the contents of the `MException` object `exceptObj` to see the cause of the error. If an error occurs between `catch` and `end`, MATLAB terminates execution unless another `try-catch` sequence has been established.

Program Termination — return

This section covers the MATLAB `return` function that enables you to terminate your program before it runs to completion.

return

`return` terminates the current sequence of commands and returns control to the invoking function or to the keyboard. `return` is also used to terminate `keyboard` mode. A called function normally transfers control to the function that invoked it when it reaches the end of the function. You can insert a `return` statement within the called function to force an early termination and to transfer control to the invoking function.

Other Data Structures

In this section...

"Multidimensional Arrays" on page 4-9
"Cell Arrays" on page 4-11
"Characters and Text" on page 4-13
"Structures" on page 4-16

Multidimensional Arrays

Multidimensional arrays in the MATLAB environment are arrays with more than two subscripts. One way of creating a multidimensional array is by calling `zeros`, `ones`, `rand`, or `randn` with more than two arguments. For example,

```
R = randn(3,4,5);
```

creates a 3-by-4-by-5 array with a total of `3*4*5 = 60` normally distributed random elements.

A three-dimensional array might represent three-dimensional physical data, say the temperature in a room, sampled on a rectangular grid. Or it might represent a sequence of matrices, $A^{(k)}$, or samples of a time-dependent matrix, $A(t)$. In these latter cases, the (i, j)th element of the kth matrix, or the t_kth matrix, is denoted by `A(i,j,k)`.

MATLAB and Dürer's versions of the magic square of order 4 differ by an interchange of two columns. Many different magic squares can be generated by interchanging columns. The statement

```
p = perms(1:4);
```

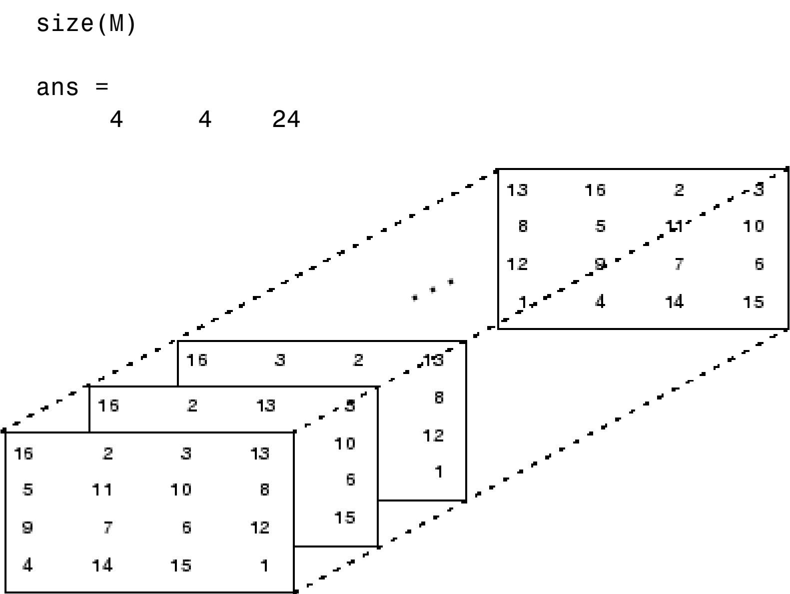
generates the 4! = 24 permutations of `1:4`. The `k`th permutation is the row vector `p(k,:)`. Then

```
A = magic(4);
M = zeros(4,4,24);
```

```
for k = 1:24
   M(:,:,k) = A(:,p(k,:));
end
```

stores the sequence of 24 magic squares in a three-dimensional array, `M`. The size of `M` is

```
size(M)

ans =
     4     4    24
```



Note The order of the matrices shown in this illustration might differ from your results. The `perms` function always returns all permutations of the input vector, but the order of the permutations might be different for different MATLAB versions.

The statement

```
sum(M,d)
```

computes sums by varying the `d`th subscript. So

```
sum(M,1)
```

is a 1-by-4-by-24 array containing 24 copies of the row vector

```
34    34    34    34
```

and

```
sum(M,2)
```

is a 4-by-1-by-24 array containing 24 copies of the column vector

```
34
34
34
34
```

Finally,

```
S = sum(M,3)
```

adds the 24 matrices in the sequence. The result has size 4-by-4-by-1, so it looks like a 4-by-4 array:

```
S =
   204   204   204   204
   204   204   204   204
   204   204   204   204
   204   204   204   204
```

Cell Arrays

Cell arrays in MATLAB are multidimensional arrays whose elements are copies of other arrays. A cell array of empty matrices can be created with the `cell` function. But, more often, cell arrays are created by enclosing a miscellaneous collection of things in curly braces, `{}`. The curly braces are also used with subscripts to access the contents of various cells. For example,

```
C = {A sum(A) prod(prod(A))}
```

produces a 1-by-3 cell array. The three cells contain the magic square, the row vector of column sums, and the product of all its elements. When `C` is displayed, you see

```
C =
```

```
    [4x4 double]    [1x4 double]    [20922789888000]
```

This is because the first two cells are too large to print in this limited space, but the third cell contains only a single number, 16!, so there is room to print it.

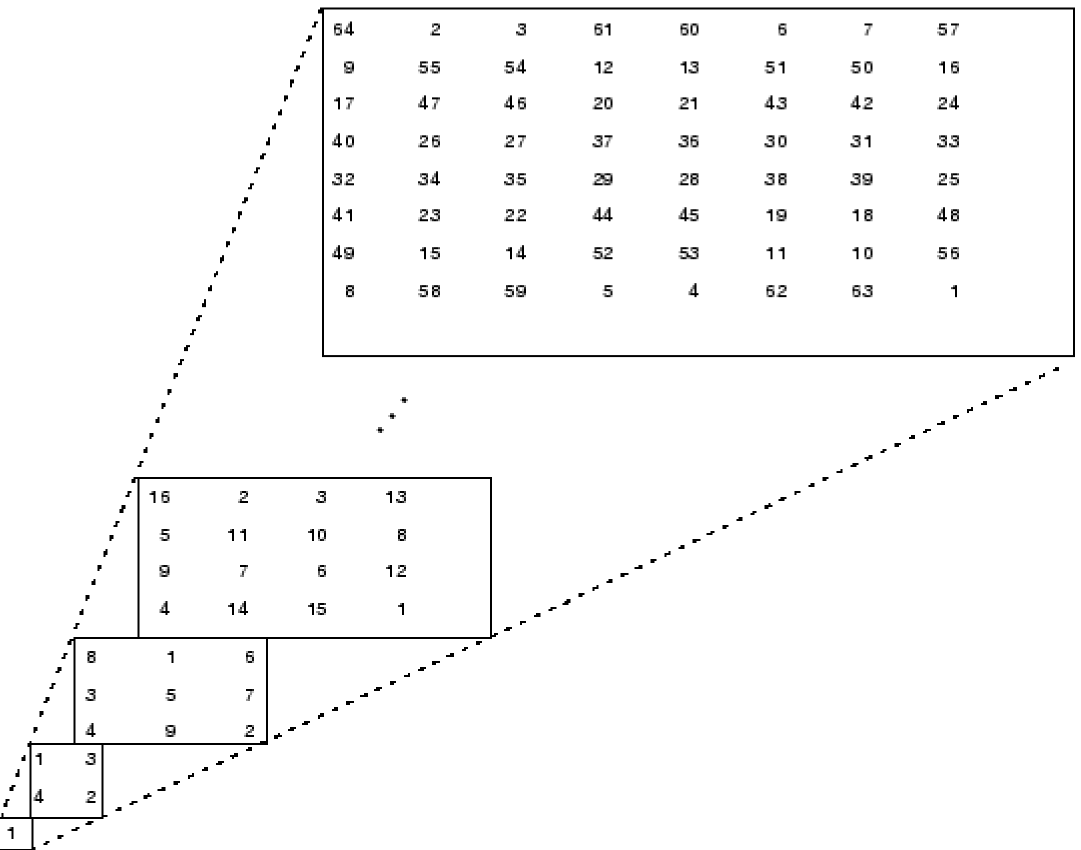
Here are two important points to remember. First, to retrieve the contents of one of the cells, use subscripts in curly braces. For example, `C{1}` retrieves the magic square and `C{3}` is 16!. Second, cell arrays contain *copies* of other arrays, not *pointers* to those arrays. If you subsequently change `A`, nothing happens to `C`.

You can use three-dimensional arrays to store a sequence of matrices of the *same* size. Cell arrays can be used to store a sequence of matrices of *different* sizes. For example,

```
M = cell(8,1);
for n = 1:8
   M{n} = magic(n);
end
M
```

produces a sequence of magic squares of different order:

```
M =
    [           1]
    [ 2x2  double]
    [ 3x3  double]
    [ 4x4  double]
    [ 5x5  double]
    [ 6x6  double]
    [ 7x7  double]
    [ 8x8  double]
```



You can retrieve the 4-by-4 magic square matrix with

```
M{4}
```

Characters and Text

Enter text into MATLAB using single quotes. For example,

```
s = 'Hello'
```

The result is not the same kind of numeric matrix or array you have been dealing with up to now. It is a 1-by-5 character array.

Internally, the characters are stored as numbers, but not in floating-point format. The statement

```
a = double(s)
```

converts the character array to a numeric matrix containing floating-point representations of the ASCII codes for each character. The result is

```
a =
    72    101    108    108    111
```

The statement

```
s = char(a)
```

reverses the conversion.

Converting numbers to characters makes it possible to investigate the various fonts available on your computer. The printable characters in the basic ASCII character set are represented by the integers `32:127`. (The integers less than 32 represent nonprintable control characters.) These integers are arranged in an appropriate 6-by-16 array with

```
F = reshape(32:127,16,6)';
```

The printable characters in the extended ASCII character set are represented by `F+128`. When these integers are interpreted as characters, the result depends on the font currently being used. Type the statements

```
char(F)
char(F+128)
```

and then vary the font being used for the Command Window. Select **Preferences** from the **File** menu and then click **Fonts** to change the font. If you include tabs in lines of code, use a fixed-width font, such as Monospaced, to align the tab positions on different lines.

Concatenation with square brackets joins text variables together into larger strings. The statement

```
h = [s, ' world']
```

joins the strings horizontally and produces

```
h =
   Hello world
```

The statement

```
v = [s; 'world']
```

joins the strings vertically and produces

```
v =
   Hello
   world
```

Note that a blank has to be inserted before the `'w'` in `h` and that both words in `v` have to have the same length. The resulting arrays are both character arrays; `h` is 1-by-11 and `v` is 2-by-5.

To manipulate a body of text containing lines of different lengths, you have two choices—a padded character array or a cell array of strings. When creating a character array, you must make each row of the array the same length. (Pad the ends of the shorter rows with spaces.) The `char` function does this padding for you. For example,

```
S = char('A','rolling','stone','gathers','momentum.')
```

produces a 5-by-9 character array:

```
S =
A
rolling
stone
gathers
momentum.
```

Alternatively, you can store the text in a cell array. For example,

```
C = {'A';'rolling';'stone';'gathers';'momentum.'}
```

creates a 5-by-1 cell array that requires no padding because each row of the array can have a different length:

```
C =
    'A'
    'rolling'
    'stone'
    'gathers'
    'momentum.'
```

You can convert a padded character array to a cell array of strings with

```
C = cellstr(S)
```

and reverse the process with

```
S = char(C)
```

Structures

Structures are multidimensional MATLAB arrays with elements accessed by textual *field designators*. For example,

```
S.name = 'Ed Plum';
S.score = 83;
S.grade = 'B+'
```

creates a scalar structure with three fields:

```
S =
     name: 'Ed Plum'
    score: 83
    grade: 'B+'
```

Like everything else in the MATLAB environment, structures are arrays, so you can insert additional elements. In this case, each element of the array is a structure with several fields. The fields can be added one at a time,

```
S(2).name = 'Toni Miller';
S(2).score = 91;
S(2).grade = 'A-';
```

or an entire element can be added with a single statement:

```
S(3) = struct('name','Jerry Garcia',...
               'score',70,'grade','C')
```

Now the structure is large enough that only a summary is printed:

```
S =
1x3 struct array with fields:
    name
    score
    grade
```

There are several ways to reassemble the various fields into other MATLAB arrays. They are mostly based on the notation of a *comma-separated list*. If you type

```
S.score
```

it is the same as typing

```
S(1).score, S(2).score, S(3).score
```

which is a comma-separated list.

If you enclose the expression that generates such a list within square brackets, MATLAB stores each item from the list in an array. In this example, MATLAB creates a numeric row vector containing the `score` field of each element of structure array `S`:

```
scores = [S.score]
scores =
    83    91    70

avg_score = sum(scores)/length(scores)
avg_score =
   81.3333
```

To create a character array from one of the text fields (`name`, for example), call the `char` function on the comma-separated list produced by `S.name`:

```
names = char(S.name)
names =
   Ed Plum
   Toni Miller
   Jerry Garcia
```

Similarly, you can create a cell array from the `name` fields by enclosing the list-generating expression within curly braces:

```
names = {S.name}
names =
    'Ed Plum'    'Toni Miller'    'Jerry Garcia'
```

To assign the fields of each element of a structure array to separate variables outside of the structure, specify each output to the left of the equals sign, enclosing them all within square brackets:

```
[N1 N2 N3] = S.name
N1 =
   Ed Plum
N2 =
   Toni Miller
N3 =
   Jerry Garcia
```

Dynamic Field Names

The most common way to access the data in a structure is by specifying the name of the field that you want to reference. Another means of accessing structure data is to use dynamic field names. These names express the field as a variable expression that MATLAB evaluates at run-time. The dot-parentheses syntax shown here makes `expression` a dynamic field name:

```
structName.(expression)
```

Index into this field using the standard MATLAB indexing syntax. For example, to evaluate `expression` into a field name and obtain the values of that field at columns `1` through `25` of row `7`, use

```
structName.(expression)(7,1:25)
```

Dynamic Field Names Example. The `avgscore` function shown below computes an average test score, retrieving information from the `testscores` structure using dynamic field names:

```
function avg = avgscore(testscores, student, first, last)
for k = first:last
   scores(k) = testscores.(student).week(k);
```

```
end
avg = sum(scores)/(last - first + 1);
```

You can run this function using different values for the dynamic field `student`. First, initialize the structure that contains scores for a 25-week period:

```
testscores.Ann_Lane.week(1:25) = ...
  [95 89 76 82 79 92 94 92 89 81 75 93 ...
   85 84 83 86 85 90 82 82 84 79 96 88 98];

testscores.William_King.week(1:25) = ...
  [87 80 91 84 99 87 93 87 97 87 82 89 ...
   86 82 90 98 75 79 92 84 90 93 84 78 81];
```

Now run `avgscore`, supplying the students name fields for the `testscores` structure at runtime using dynamic field names:

```
avgscore(testscores, 'Ann_Lane', 7, 22)
ans =
   85.2500

avgscore(testscores, 'William_King', 7, 22)
ans =
   87.7500
```

Scripts and Functions

In this section...

"Overview" on page 4-20
"Scripts" on page 4-21
"Functions" on page 4-22
"Types of Functions" on page 4-24
"Global Variables" on page 4-26
"Passing String Arguments to Functions" on page 4-27
"The eval Function" on page 4-28
"Function Handles" on page 4-28
"Function Functions" on page 4-29
"Vectorization" on page 4-31
"Preallocation" on page 4-32

Overview

The MATLAB product provides a powerful programming language, as well as an interactive computational environment. Files that contain code in the MATLAB language are called M-files. You create M-files using a text editor, then use them as you would any other MATLAB function or command.

There are two kinds of M-files:

- Scripts, which do not accept input arguments or return output arguments. They operate on data in the workspace.
- Functions, which can accept input arguments and return output arguments. Internal variables are local to the function.

If you're a new MATLAB programmer, just create the M-files that you want to try out in the current directory. As you develop more of your own M-files, you will want to organize them into other directories and personal toolboxes that you can add to your MATLAB search path.

If you duplicate function names, MATLAB executes the one that occurs first in the search path.

To view the contents of an M-file, for example, `myfunction.m`, use

```
type myfunction
```

Scripts

When you invoke a *script*, MATLAB simply executes the commands found in the file. Scripts can operate on existing data in the workspace, or they can create new data on which to operate. Although scripts do not return output arguments, any variables that they create remain in the workspace, to be used in subsequent computations. In addition, scripts can produce graphical output using functions like `plot`.

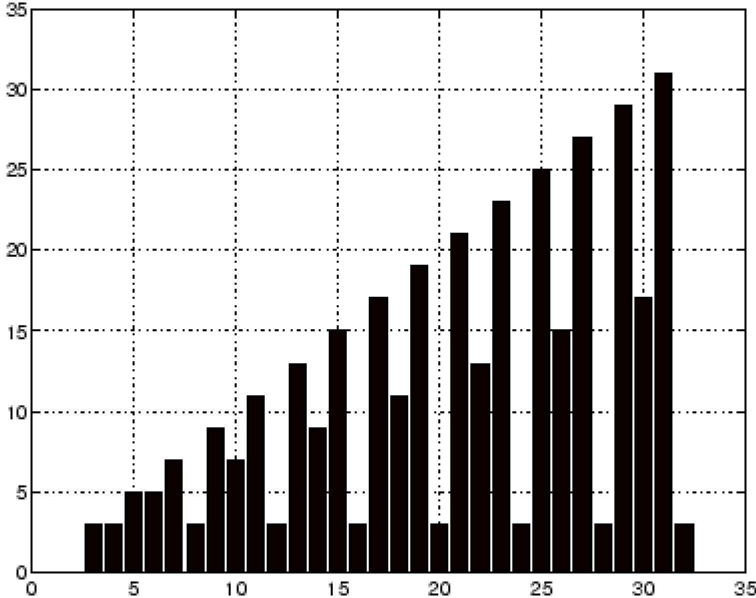
For example, create a file called `magicrank.m` that contains these MATLAB commands:

```
% Investigate the rank of magic squares
r = zeros(1,32);
for n = 3:32
   r(n) = rank(magic(n));
end
r
bar(r)
```

Typing the statement

```
magicrank
```

causes MATLAB to execute the commands, compute the rank of the first 30 magic squares, and plot a bar graph of the result. After execution of the file is complete, the variables `n` and `r` remain in the workspace.



Functions

Functions are M-files that can accept input arguments and return output arguments. The names of the M-file and of the function should be the same. Functions operate on variables within their own workspace, separate from the workspace you access at the MATLAB command prompt.

A good example is provided by `rank`. The M-file `rank.m` is available in the directory

```
toolbox/matlab/matfun
```

You can see the file with

```
type rank
```

Here is the file:

```
function r = rank(A,tol)
%   RANK Matrix rank.
%   RANK(A) provides an estimate of the number of linearly
```

```
%   independent rows or columns of a matrix A.
%   RANK(A,tol) is the number of singular values of A
%   that are larger than tol.
%   RANK(A) uses the default tol = max(size(A)) * norm(A) * eps.

s = svd(A);
if nargin==1
   tol = max(size(A)') * max(s) * eps;
end
r = sum(s > tol);
```

The first line of a function M-file starts with the keyword `function`. It gives the function name and order of arguments. In this case, there are up to two input arguments and one output argument.

The next several lines, up to the first blank or executable line, are comment lines that provide the help text. These lines are printed when you type

```
help rank
```

The first line of the help text is the H1 line, which MATLAB displays when you use the `lookfor` command or request `help` on a directory.

The rest of the file is the executable MATLAB code defining the function. The variable `s` introduced in the body of the function, as well as the variables on the first line, `r`, `A` and `tol`, are all *local* to the function; they are separate from any variables in the MATLAB workspace.

This example illustrates one aspect of MATLAB functions that is not ordinarily found in other programming languages—a variable number of arguments. The `rank` function can be used in several different ways:

```
rank(A)
r = rank(A)
r = rank(A,1.e-6)
```

Many M-files work this way. If no output argument is supplied, the result is stored in `ans`. If the second input argument is not supplied, the function computes a default value. Within the body of the function, two quantities named `nargin` and `nargout` are available that tell you the number of input

and output arguments involved in each particular use of the function. The `rank` function uses `nargin`, but does not need to use `nargout`.

Types of Functions

MATLAB offers several different types of functions to use in your programming.

Anonymous Functions

An *anonymous function* is a simple form of the MATLAB function that does not require an M-file. It consists of a single MATLAB expression and any number of input and output arguments. You can define an anonymous function right at the MATLAB command line, or within an M-file function or script. This gives you a quick means of creating simple functions without having to create M-files each time.

The syntax for creating an anonymous function from an expression is

```
f = @(arglist)expression
```

The statement below creates an anonymous function that finds the square of a number. When you call this function, MATLAB assigns the value you pass in to variable `x`, and then uses `x` in the equation `x.^2`:

```
sqr = @(x) x.^2;
```

To execute the `sqr` function defined above, type

```
a = sqr(5)
a =
   25
```

Primary and Subfunctions

All functions that are not anonymous must be defined within an M-file. Each M-file has a required *primary function* that appears first in the file, and any number of *subfunctions* that follow the primary. Primary functions have a wider scope than subfunctions. That is, primary functions can be invoked from outside of their M-file (from the MATLAB command line or from

functions in other M-files) while subfunctions cannot. Subfunctions are visible only to the primary function and other subfunctions within their own M-file.

The `rank` function shown in the section on "Functions" on page 4-22 is an example of a primary function.

Private Functions

A *private function* is a type of primary M-file function. Its unique characteristic is that it is visible only to a limited group of other functions. This type of function can be useful if you want to limit access to a function, or when you choose not to expose the implementation of a function.

Private functions reside in subdirectories with the special name `private`. They are visible only to functions in the parent directory. For example, assume the directory `newmath` is on the MATLAB search path. A subdirectory of `newmath` called `private` can contain functions that only the functions in `newmath` can call.

Because private functions are invisible outside the parent directory, they can use the same names as functions in other directories. This is useful if you want to create your own version of a particular function while retaining the original in another directory. Because MATLAB looks for private functions before standard M-file functions, it will find a private function named `test.m` before a nonprivate M-file named `test.m`.

Nested Functions

You can define functions within the body of any M-file function. These are said to be *nested* within the outer function. A nested function contains any or all of the components of any other M-file function. In this example, function `B` is nested in function `A`:

```
function x = A(p1, p2)
...
B(p2)
   function y = B(p3)
   ...
   end
...
end
```

Like other functions, a nested function has its own workspace where variables used by the function are stored. But it also has access to the workspaces of all functions in which it is nested. So, for example, a variable that has a value assigned to it by the primary function can be read or overwritten by a function nested at any level within the primary. Similarly, a variable that is assigned in a nested function can be read or overwritten by any of the functions containing that function.

Function Overloading

Overloaded functions act the same way as overloaded functions in most computer languages. Overloaded functions are useful when you need to create a function that responds to different types of inputs accordingly. For instance, you might want one of your functions to accept both double-precision and integer input, but to handle each type somewhat differently. You can make this difference invisible to the user by creating two separate functions having the same name, and designating one to handle `double` types and one to handle integers. When you call the function, MATLAB chooses which M-file to dispatch to based on the type of the input arguments.

Global Variables

If you want more than one function to share a single copy of a variable, simply declare the variable as `global` in all the functions. Do the same thing at the command line if you want the base workspace to access the variable. The global declaration must occur before the variable is actually used in a function. Although it is not required, using capital letters for the names of global variables helps distinguish them from other variables. For example, create an M-file called `falling.m`:

```
function h = falling(t)
global GRAVITY
h = 1/2*GRAVITY*t.^2;
```

Then interactively enter the statements

```
global GRAVITY
GRAVITY = 32;
y = falling((0:.1:5)');
```

The two global statements make the value assigned to `GRAVITY` at the command prompt available inside the function. You can then modify `GRAVITY` interactively and obtain new solutions without editing any files.

Passing String Arguments to Functions

You can write MATLAB functions that accept string arguments without the parentheses and quotes. That is, MATLAB interprets

```
foo a b c
```

as

```
foo('a','b','c')
```

However, when you use the unquoted form, MATLAB cannot return output arguments. For example,

```
legend apples oranges
```

creates a legend on a plot using the strings `apples` and `oranges` as labels. If you want the `legend` command to return its output arguments, then you must use the quoted form:

```
[legh,objh] = legend('apples','oranges');
```

In addition, you must use the quoted form if any of the arguments is not a string.

Caution While the unquoted syntax is convenient, in some cases it can be used incorrectly without causing MATLAB to generate an error.

Constructing String Arguments in Code

The quoted form enables you to construct string arguments within the code. The following example processes multiple data files, `August1.dat`, `August2.dat`, and so on. It uses the function `int2str`, which converts an integer to a character, to build the filename:

```
for d = 1:31
```

```
    s = ['August' int2str(d) '.dat'];
    load(s)
    % Code to process the contents of the d-th file
end
```

The eval Function

The `eval` function works with text variables to implement a powerful text macro facility. The expression or statement

```
eval(s)
```

uses the MATLAB interpreter to evaluate the expression or execute the statement contained in the text string `s`.

The example of the previous section could also be done with the following code, although this would be somewhat less efficient because it involves the full interpreter, not just a function call:

```
for d = 1:31
    s = ['load August' int2str(d) '.dat'];
    eval(s)
    % Process the contents of the d-th file
end
```

Function Handles

You can create a handle to any MATLAB function and then use that handle as a means of referencing the function. A function handle is typically passed in an argument list to other functions, which can then execute, or *evaluate*, the function using the handle.

Construct a function handle in MATLAB using the *at* sign, `@`, before the function name. The following example creates a function handle for the `sin` function and assigns it to the variable `fhandle`:

```
fhandle = @sin;
```

You can call a function by means of its handle in the same way that you would call the function using its name. The syntax is

```
fhandle(arg1, arg2, ...);
```

The function `plot_fhandle`, shown below, receives a function handle and data, generates y-axis data using the function handle, and plots it:

```
function x = plot_fhandle(fhandle, data)
plot(data, fhandle(data))
```

When you call `plot_fhandle` with a handle to the `sin` function and the argument shown below, the resulting evaluation produces a sine wave plot:

```
plot_fhandle(@sin, -pi:0.01:pi)
```

Function Functions

A class of functions called “function functions” works with nonlinear functions of a scalar variable. That is, one function works on another function. The function functions include

- Zero finding
- Optimization
- Quadrature
- Ordinary differential equations

MATLAB represents the nonlinear function by a function M-file. For example, here is a simplified version of the function `humps` from the `matlab/demos` directory:

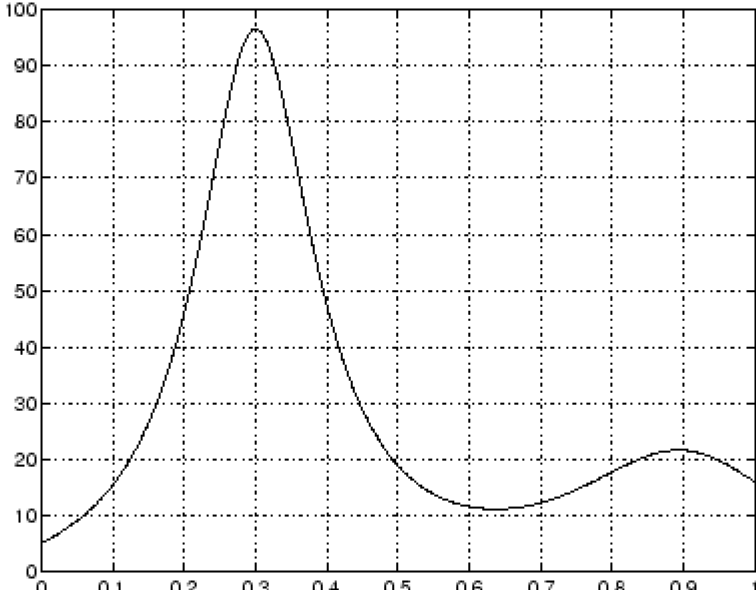
```
function y = humps(x)
y = 1./((x-.3).^2 + .01) + 1./((x-.9).^2 + .04) - 6;
```

Evaluate this function at a set of points in the interval $0 \le x \le 1$ with

```
x = 0:.002:1;
y = humps(x);
```

Then plot the function with

```
plot(x,y)
```



The graph shows that the function has a local minimum near $x = 0.6$. The function `fminsearch` finds the *minimizer*, the value of x where the function takes on this minimum. The first argument to `fminsearch` is a function handle to the function being minimized and the second argument is a rough guess at the location of the minimum:

```
p = fminsearch(@humps,.5)
p =
    0.6370
```

To evaluate the function at the minimizer,

```
humps(p)

ans =
   11.2528
```

Numerical analysts use the terms *quadrature* and *integration* to distinguish between numerical approximation of definite integrals and numerical integration of ordinary differential equations. MATLAB quadrature routines are `quad` and `quadl`. The statement

```
Q = quadl(@humps,0,1)
```

computes the area under the curve in the graph and produces

```
Q =
   29.8583
```

Finally, the graph shows that the function is never zero on this interval. So, if you search for a zero with

```
z = fzero(@humps,.5)
```

you will find one outside the interval

```
z =
   -0.1316
```

Vectorization

One way to make your MATLAB programs run faster is to vectorize the algorithms you use in constructing the programs. Where other programming languages might use `for` loops or `DO` loops, MATLAB can use vector or matrix operations. A simple example involves creating a table of logarithms:

```
x = .01;
for k = 1:1001
   y(k) = log10(x);
   x = x + .01;
end
```

A vectorized version of the same code is

```
x = .01:.01:10;
y = log10(x);
```

For more complicated code, vectorization options are not always so obvious.

For More Information See “Performance” in the MATLAB Programming Fundamentals documentation for other techniques that you can use.

Preallocation

If you cannot vectorize a piece of code, you can make your `for` loops go faster by preallocating any vectors or arrays in which output results are stored. For example, this code uses the function `zeros` to preallocate the vector created in the `for` loop. This makes the `for` loop execute significantly faster:

```
r = zeros(32,1);
for n = 1:32
    r(n) = rank(magic(n));
end
```

Without the preallocation in the previous example, the MATLAB interpreter enlarges the `r` vector by one element each time through the loop. Vector preallocation eliminates this step and results in faster execution.

Object-Oriented Programming

In this section...

"MATLAB Classes and Objects" on page 4-33

"Learn About Defining MATLAB Classes" on page 4-33

MATLAB Classes and Objects

MATLAB object-oriented programming capabilities enable you to develop and maintain large application and define complex data structures that integrate seamlessly into the MATLAB environment. Some of the features include:

- Support for value and handle (reference) classes
- Definition of events and listeners
- Class introspection
- JIT/Accelerator support for classes to improve performance

Learn About Defining MATLAB Classes

For complete information on using and creating MATLAB classes, see *Object-Oriented Programming* in the user-guide documentation.

Data Analysis

- "Introduction" on page 5-2
- "Preprocessing Data" on page 5-3
- "Summarizing Data" on page 5-10
- "Visualizing Data" on page 5-14
- "Modeling Data" on page 5-27

Introduction

Every data analysis has some standard components:

- Preprocessing — Consider outliers and missing values, and smooth data to identify possible models.
- Summarizing — Compute basic statistics to describe the overall location, scale, and shape of the data.
- Visualizing — Plot data to identify patterns and trends.
- Modeling — Give data trends fuller descriptions, suitable for predicting new values.

Data analysis moves among these components with two basic goals in mind:

1. Describe the patterns in the data with simple models that lead to accurate predictions.
2. Understand the relationships among variables that lead to the model.

This section of the Getting Started guide explains how to carry out a basic data analysis in the MATLAB environment.

Preprocessing Data

In this section...

"Overview" on page 5-3

"Loading the Data" on page 5-3

"Missing Data" on page 5-3

"Outliers" on page 5-4

"Smoothing and Filtering" on page 5-6

Overview

Begin a data analysis by loading data into suitable MATLAB container variables and sorting out the "good" data from the "bad." This is a preliminary step that assures meaningful conclusions in subsequent parts of the analysis.

Note This section begins a data analysis that is continued in "Summarizing Data" on page 5-10, "Visualizing Data" on page 5-14, and "Modeling Data" on page 5-27.

Loading the Data

Begin by loading the data in `count.dat`:

```
load count.dat
```

The 24-by-3 array `count` contains hourly traffic counts (the rows) at three intersections (the columns) for a single day.

See "Importing and Exporting Data" in the MATLAB Data Analysis documentation for more information on storing data in MATLAB variables for analysis.

Missing Data

The MATLAB `NaN` (Not a Number) value is normally used to represent missing data. `NaN` values allow variables with missing data to maintain their

structure—in this case, 24-by-1 vectors with consistent indexing across all three intersections.

Check the data at the third intersection for NaN values using the isnan function:

```
c3 = count(:,3); % Data at intersection 3
c3NaNCount = sum(isnan(c3))
c3NaNCount =
     0
```

isnan returns a logical vector the same size as c3, with entries indicating the presence (1) or absence (0) of NaN values for each of the 24 elements in the data. In this case, the logical values sum to 0, so there are no NaN values in the data.

NaN values are introduced into the data in the section on "Outliers" on page 5-4.

See "Missing Data" in the MATLAB Data Analysis documentation for more information on handling missing data.

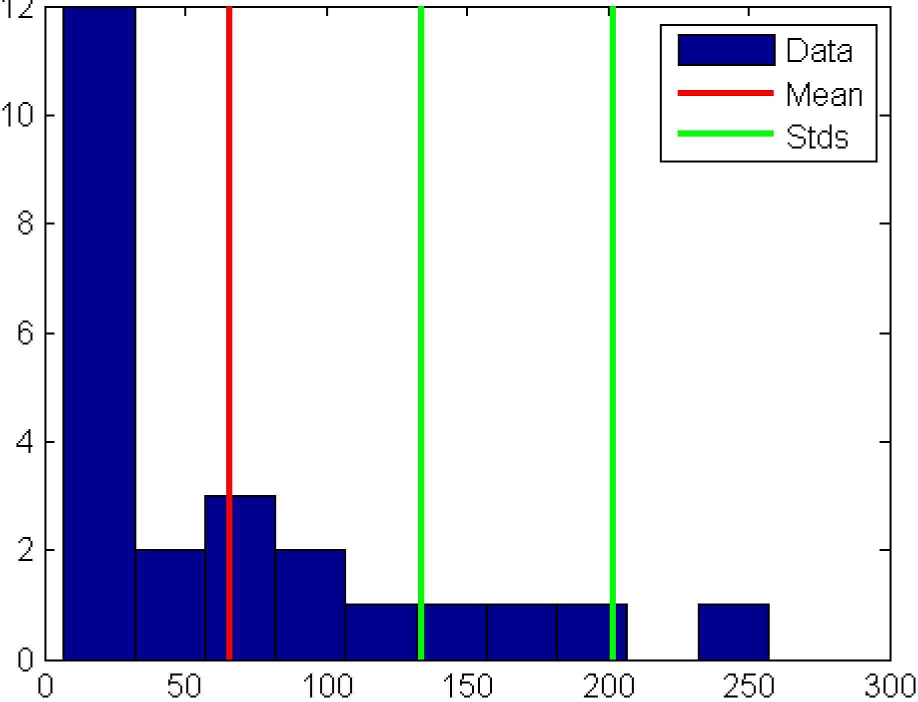
Outliers

Outliers are data values that are dramatically different from patterns in the rest of the data. They may be due to measurement error, or they may represent significant features in the data. Identifying outliers, and deciding what to do with them, depends on an understanding of the data and its source.

One common method for identifying outliers is to look for values more than a certain number of standard deviations σ from the mean μ. The following code plots a histogram of the data at the third intersection together with lines at μ and $\mu + n\sigma$, for $n = 1, 2$:

```
bin_counts = hist(c3); % Histogram bin counts
N = max(bin_counts); % Maximum bin count
mu3 = mean(c3); % Data mean
sigma3 = std(c3); % Data standard deviation

hist(c3) % Plot histogram
hold on
```

```
plot([mu3 mu3],[0 N],'r','LineWidth',2) % Mean
X = repmat(mu3+(1:2)*sigma3,2,1);
Y = repmat([0;N],1,2);
plot(X,Y,'g','LineWidth',2) % Standard deviations
legend('Data','Mean','Stds')
hold off
```



The plot shows that some of the data are more than two standard deviations above the mean. If you identify these data as errors (not features), replace them with `NaN` values as follows:

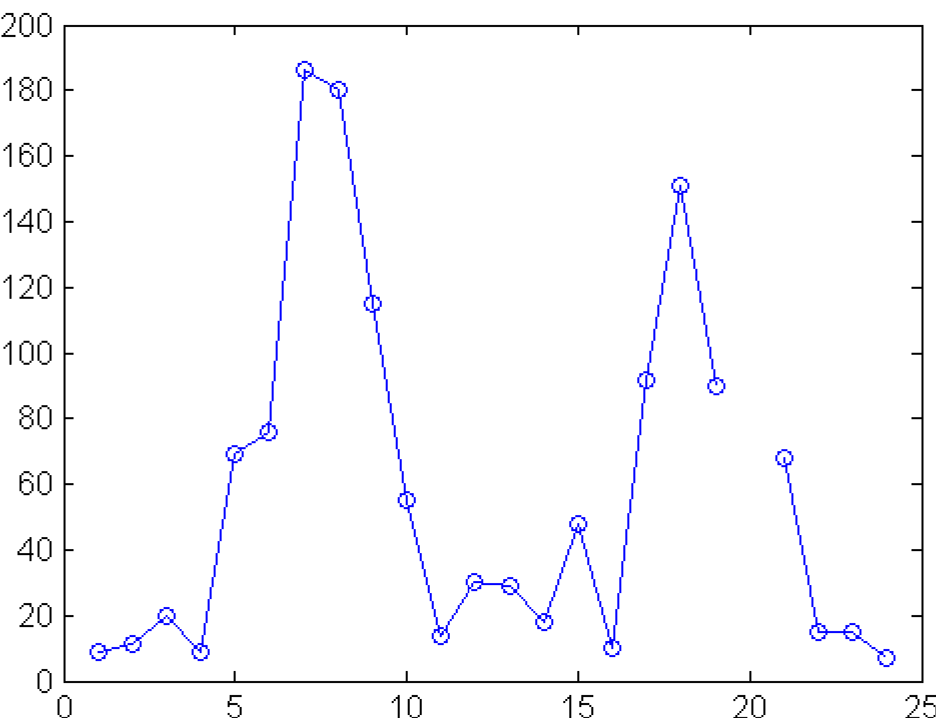
```
outliers = (c3 - mu3) > 2*sigma3;
c3m = c3; % Copy c3 to c3m
c3m(outliers) = NaN; % Add NaN values
```

See "Inconsistent Data" in the MATLAB Data Analysis documentation for more information on handling outliers.

Smoothing and Filtering

A time-series plot of the data at the third intersection (with the outlier removed in "Outliers" on page 5-4) results in the following plot:

```
plot(c3m,'o-')
hold on
```



The `NaN` value at hour 20 appears as a gap in the plot. This handling of `NaN` values is typical of MATLAB plotting functions.

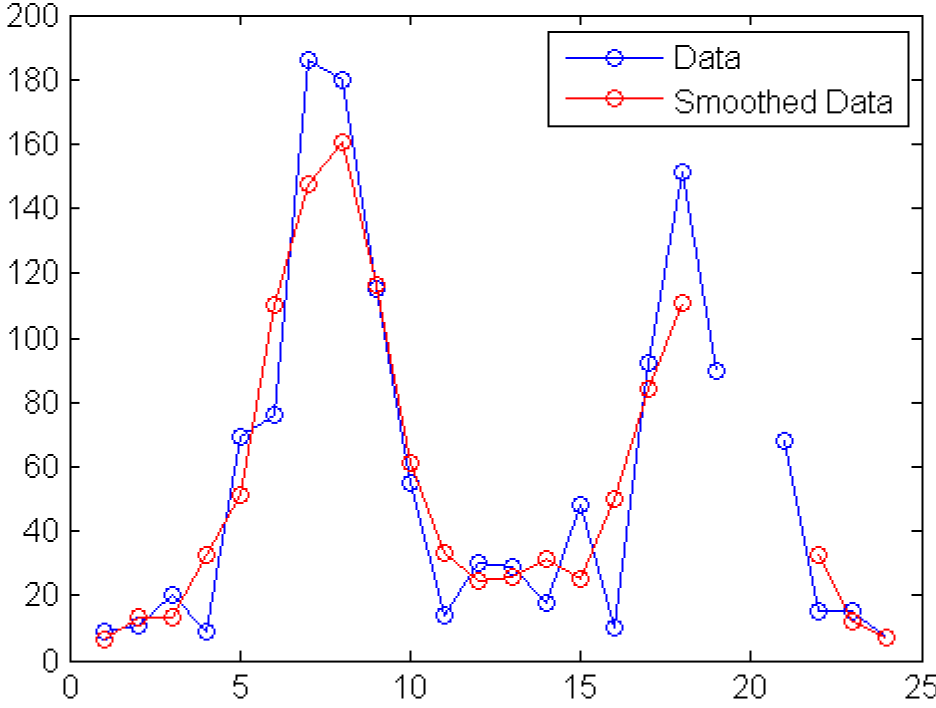
Noisy data shows random variations about expected values. You may want to smooth the data to reveal its main features before building a model. Two basic assumptions underlie smoothing:

- The relationship between the predictor (time) and the response (traffic volume) is smooth.

- The smoothing algorithm results in values that are better estimates of expected values because the noise has been reduced.

Apply a simple moving average smoother to the data using the MATLAB `convn` function:

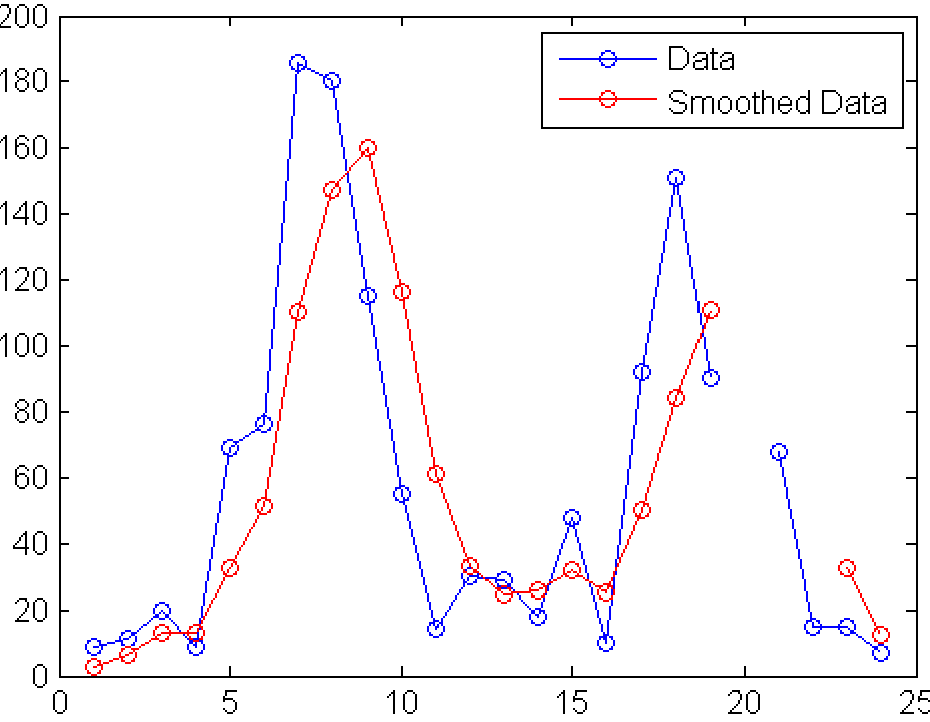
```
span = 3; % Size of the averaging window
window = ones(span,1)/span;
smoothed_c3m = convn(c3m,window,'same');

h = plot(smoothed_c3m,'ro-');
legend('Data','Smoothed Data')
```



The extent of the smoothing is controlled with the variable `span`. The averaging calculation returns `NaN` values whenever the smoothing window includes the `NaN` value in the data, thus increasing the size of the gap in the smoothed data.

The `filter` function is also used for smoothing data:

```
smoothed2_c3m = filter(window,1,c3m);

delete(h)
plot(smoothed2_c3m,'ro-');
```



The smoothed data are shifted from the previous plot. `convn` with the `'same'` parameter returns the central part of the convolution, the same length as the data. `filter` returns the initial part of the convolution, the same length as the data. Otherwise, the algorithms are identical.

Smoothing estimates the center of the distribution of response values at each value of the predictor. It invalidates a basic assumption of many fitting algorithms, namely, that *the errors at each value of the predictor are independent*. Accordingly, you can use smoothed data to *identify* a model, but avoid using smoothed data to *fit* a model.

See “Filtering Data” in the MATLAB Data Analysis documentation for more information on smoothing and filtering.

Summarizing Data

In this section...

"Overview" on page 5-10

"Measures of Location" on page 5-10

"Measures of Scale" on page 5-11

"Shape of a Distribution" on page 5-11

Overview

Many MATLAB functions enable you to summarize the overall location, scale, and shape of a data sample.

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

Note This section continues the data analysis from "Preprocessing Data" on page 5-3.

Measures of Location

Summarize the location of a data sample by finding a "typical" value. Common measures of location or "central tendency" are computed by the functions `mean`, `median`, and `mode`:

```
load count.dat
x1 = mean(count)
x1 =
   32.0000   46.5417   65.5833

x2 = median(count)
x2 =
   23.5000   36.0000   39.0000
```

```
x3 = mode(count)
x3 =
    11     9     9
```

Like all of its statistical functions, the MATLAB functions above summarize data across observations (rows) while preserving variables (columns). The functions compute the location of the data at each of the three intersections in a single call.

Measures of Scale

There are many ways to measure the scale or "dispersion" of a data sample. The MATLAB functions `max`, `min`, `std`, and `var` compute some common measures:

```
dx1 = max(count)-min(count)
dx1 =
   107   136   250

dx2 = std(count)
dx2 =
   25.3703   41.4057   68.0281

dx3 = var(count)
dx3 =
  1.0e+003 *
    0.6437    1.7144    4.6278
```

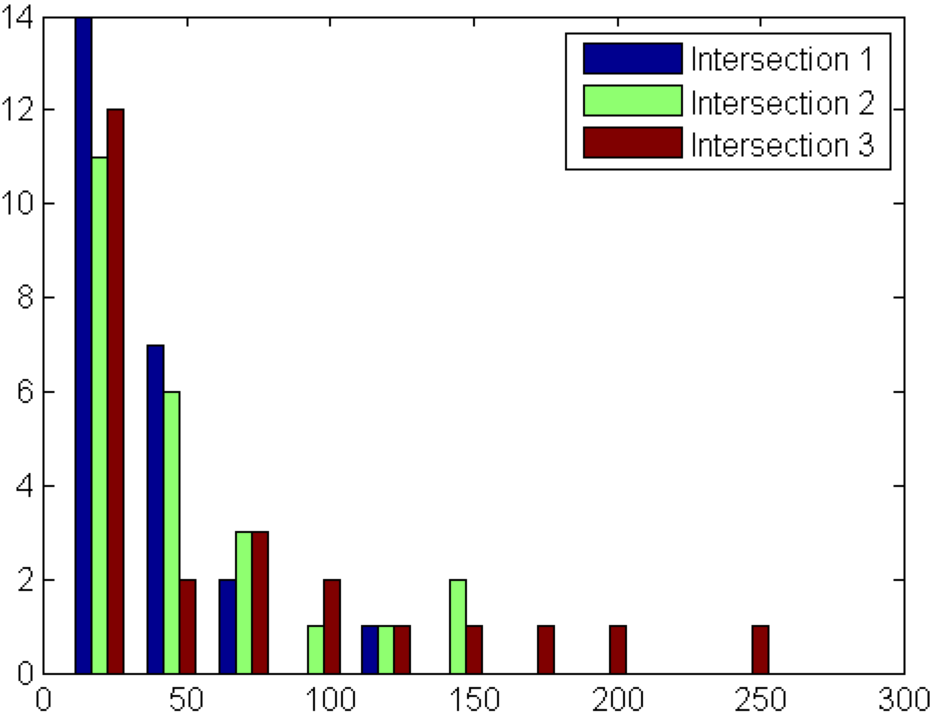
Like all of its statistical functions, the MATLAB functions above summarize data across observations (rows) while preserving variables (columns). The functions compute the scale of the data at each of the three intersections in a single call.

Shape of a Distribution

The shape of a distribution is harder to summarize than its location or scale. The MATLAB `hist` function plots a histogram that provides a visual summary:

```
figure
```

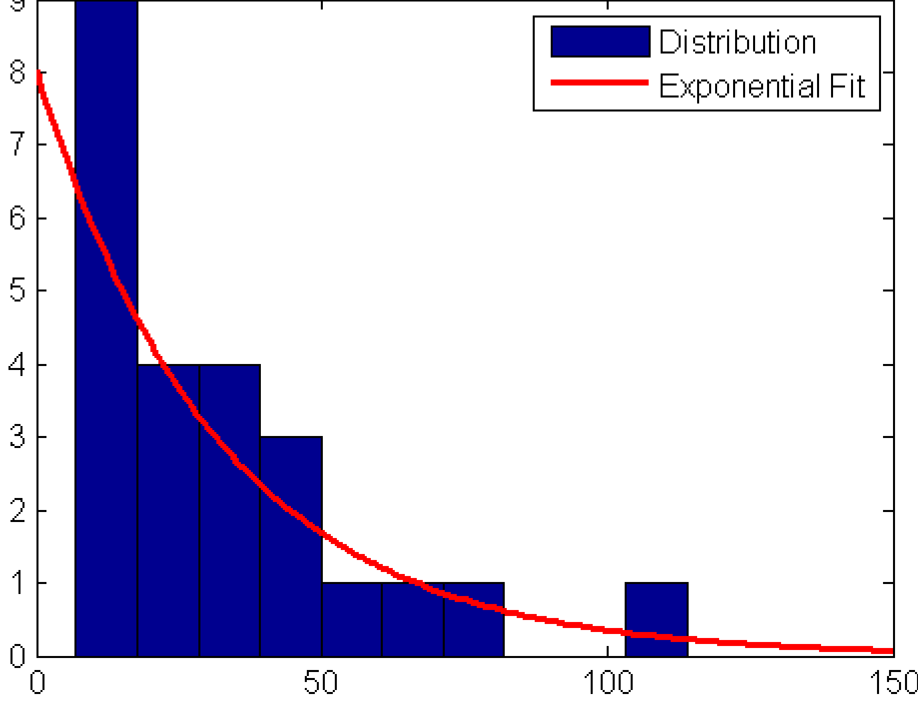
```
hist(count)
legend('Intersection 1',...
       'Intersection 2',...
       'Intersection 3')
```



Parametric models give analytic summaries of distribution shapes. Exponential distributions, with parameter `mu` given by the data mean, are a good choice for the traffic data:

```
c1 = count(:,1); % Data at intersection 1
[bin_counts,bin_locations] = hist(c1);
bin_width = bin_locations(2) - bin_locations(1);
hist_area = (bin_width)*(sum(bin_counts));

figure
hist(c1)
hold on
```

```
mu1 = mean(c1);
exp_pdf = @(t)(1/mu1)*exp(-t/mu1); % Integrates
                                    % to 1
t = 0:150;
y = exp_pdf(t);
plot(t,(hist_area)*y,'r','LineWidth',2)
legend('Distribution','Exponential Fit')
```



Methods for fitting general parametric models to data distributions are beyond the scope of this Getting Started guide. Statistics Toolbox software provides functions for computing maximum likelihood estimates of distribution parameters.

See "Descriptive Statistics" in the MATLAB Data Analysis documentation for more information on summarizing data samples.

Visualizing Data

In this section...

"Overview" on page 5-14

"2-D Scatter Plots" on page 5-14

"3-D Scatter Plots" on page 5-16

"Scatter Plot Arrays" on page 5-18

"Exploring Data in Graphs" on page 5-19

Overview

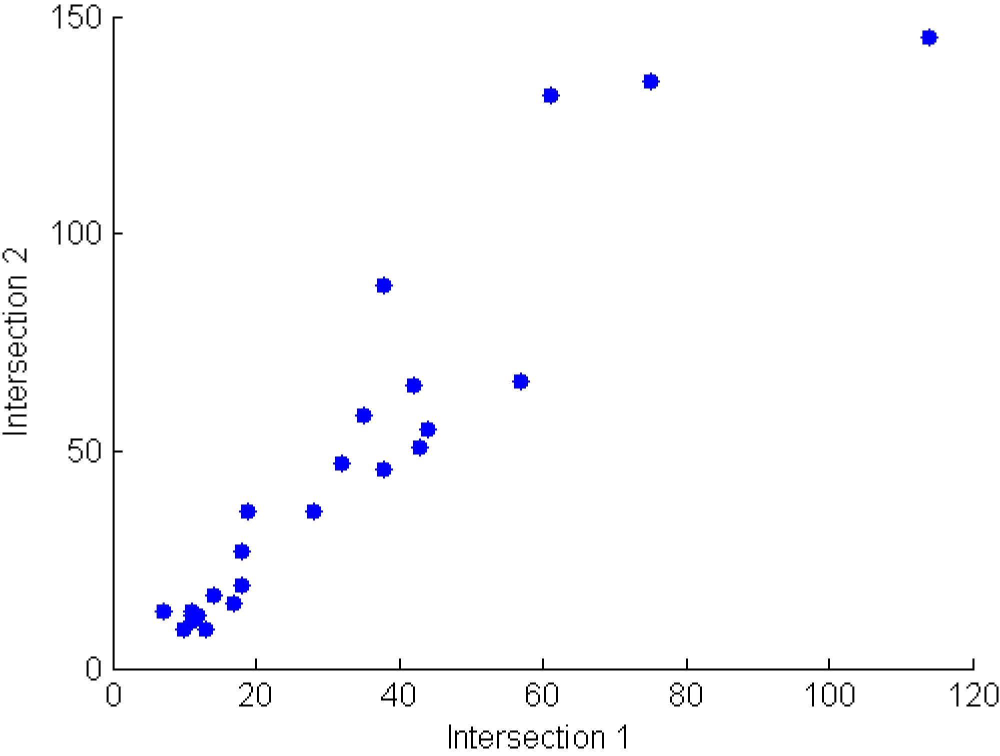
You can use many MATLAB graph types for visualizing data patterns and trends. Scatter plots, described in this section, help to visualize relationships among the traffic data at different intersections. Data exploration tools let you query and interact with individual data points on graphs.

Note This section continues the data analysis from "Summarizing Data" on page 5-10.

2-D Scatter Plots

A 2-D scatter plot, created with the `scatter` function, shows the relationship between the traffic volume at the first two intersections:

```
load count.dat
c1 = count(:,1); % Data at intersection 1
c2 = count(:,2); % Data at intersection 2

figure
scatter(c1,c2,'filled')
xlabel('Intersection 1')
ylabel('Intersection 2')
```



The *covariance*, computed by the `cov` function measures the strength of the linear relationship between the two variables (how tightly the data lies along a least-squares line through the scatter):

```
C12 = cov([c1 c2])
C12 =
  1.0e+003 *
    0.6437    0.9802
    0.9802    1.7144
```

The results are displayed in a symmetric square matrix, with the covariance of the ith and jth variables in the (i, j)th position. The ith diagonal element is the variance of the ith variable.

Covariances have the disadvantage of depending on the units used to measure the individual variables. You can divide a covariance by the standard

deviations of the variables to normalize values between +1 and –1. The `corrcoef` function computes *correlation coefficients*:

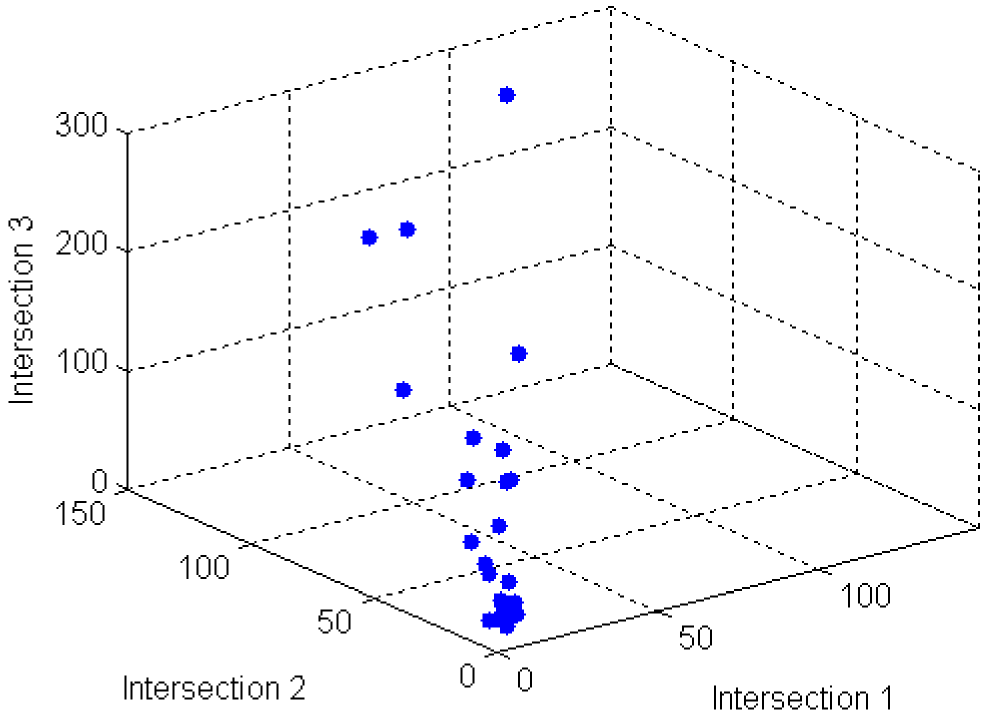
```
R12 = corrcoef([c1 c2])
R12 =
    1.0000    0.9331
    0.9331    1.0000

r12 = R12(1,2) % Correlation coefficient
r12 =
    0.9331

r12sq = r12^2 % Coefficient of determination
r12sq =
    0.8707
```

Because it is normalized, the value of the correlation coefficient is readily comparable to values for other pairs of intersections. Its square, the *coefficient of determination*, is the variance about the least-squares line divided by the variance about the mean. Thus, it is the proportion of variation in the response (in this case, the traffic volume at intersection 2) that is eliminated or statistically explained by a least-squares line through the scatter.

3-D Scatter Plots

A 3-D scatter plot, created with the `scatter3` function, shows the relationship between the traffic volume at all three intersections. Use the variables `c1`, `c2`, and `c3` that you created in the previous step:

```
figure
scatter3(c1,c2,c3,'filled')
xlabel('Intersection 1')
ylabel('Intersection 2')
zlabel('Intersection 3')
```



Measure the strength of the linear relationship among the variables in the 3-D scatter by computing eigenvalues of the covariance matrix with the `eig` function:

```
vars = eig(cov([c1 c2 c3]))
vars =
  1.0e+003 *
    0.0442
    0.1118
    6.8300

explained = max(vars)/sum(vars)
explained =
    0.9777
```

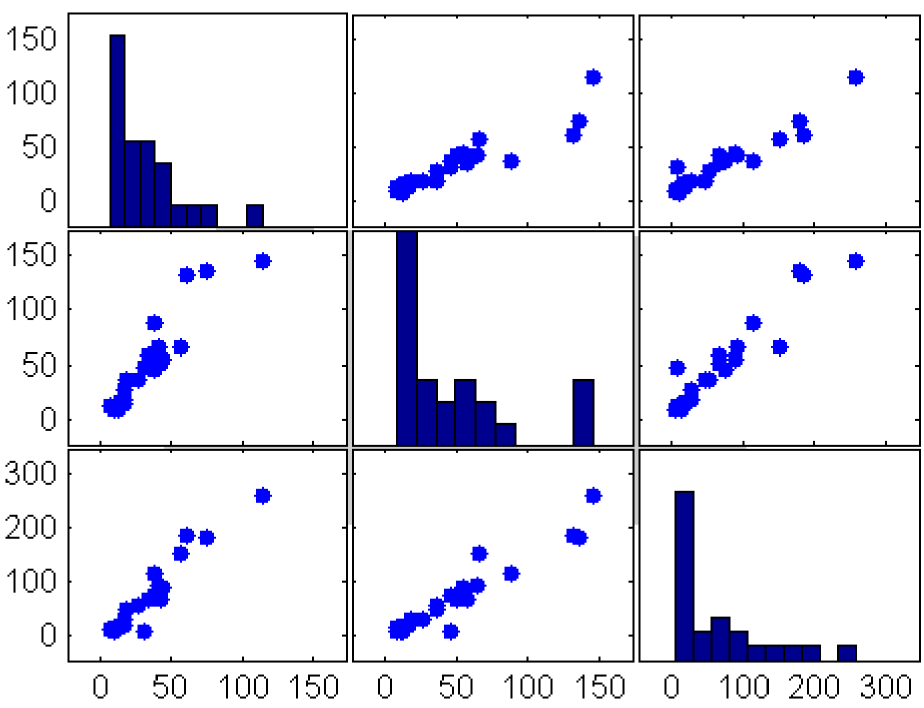
The eigenvalues are the variances along the *principal components* of the data. The variable `explained` measures the proportion of variation explained by the

first principal component, along the axis of the data. Unlike the coefficient of determination for 2-D scatters, this measure distinguishes predictor and response variables.

Scatter Plot Arrays

Use the `plotmatrix` function to make comparisons of the relationships between multiple pairs of intersections:

```
figure
plotmatrix(count)
```



The plot in the (i, j)th position of the array is a scatter with the i th variable on the vertical axis and the jth variable on the horizontal axis. The plot in the ith diagonal position is a histogram of the ith variable.

For more information on statistical visualization, see “Plotting Data” and “Interactive Data Exploration” in the MATLAB Data Analysis documentation.

Exploring Data in Graphs

Using your mouse, you can pick observations on almost any MATLAB graph with two tools from the figure toolbar:

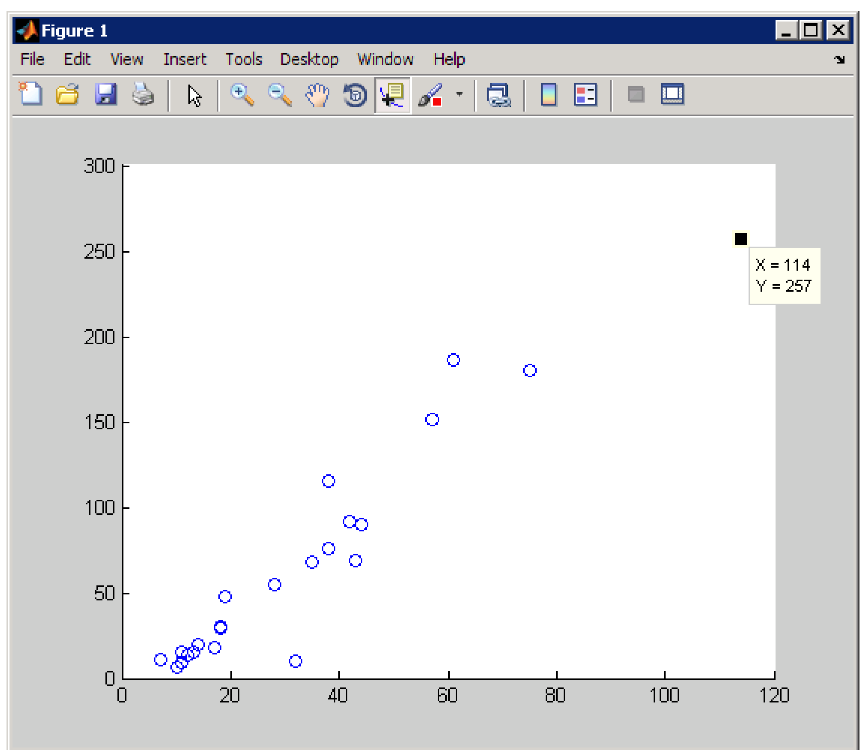
- Data Cursor
- Data Brushing

These tools each place you in exploratory modes in which you can select data points on graphs to identify their values and create workspace variables to contain specific observations. When you use data brushing, you can also copy, remove or replace the selected observations.

For example, make a scatter plot of the first and third columns of `count`:

```
load count.dat
scatter(count(:,1),count(:,3))
```

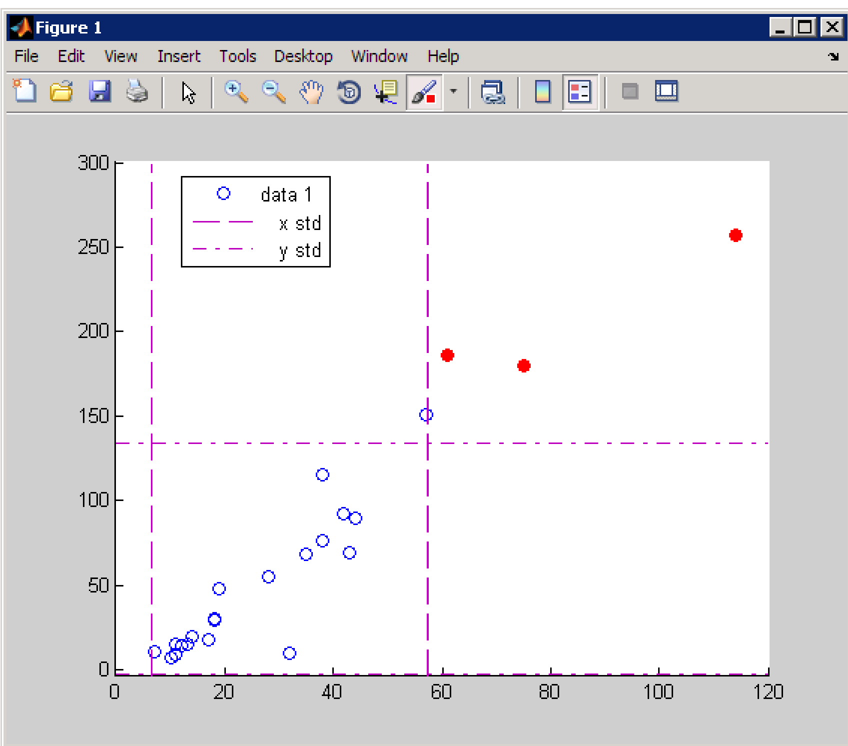
Select the Data Cursor Tool and click the right-most data point. A datatip displaying the point's x and y value is placed there.



Datatips display *x*-, *y*-, and *z*- (for 3-D plots) coordinates by default. You can drag a datatip from one data point to another to see new values or add additional datatips by right-clicking a datatip and using the context menu. You can also customize the text that datatips display using M-code. For more information, see the `datacursormode` function and "Interacting with Graphed Data" in the MATLAB Data Analysis documentation.

Data brushing is a related feature that lets you highlight one or more observations on a graph by clicking or dragging. To enter data brushing mode, click the left side of the Data Brushing tool on the figure toolbar. Clicking the arrow on the right side of the tool icon drops down a color palette for selecting the color with which to brush observations. This figure shows the same scatter plot as the previous figure, but with all observations beyond one standard deviation of the mean (as identified using the **Tools > Data Statistics** GUI) brushed in red.

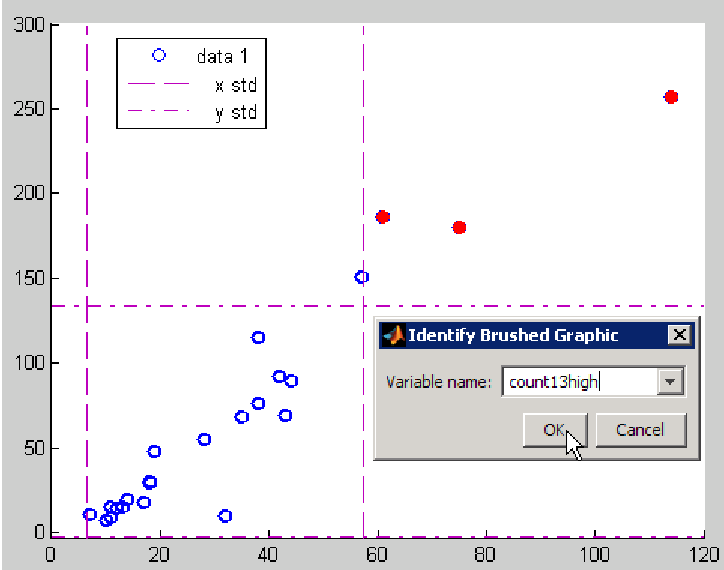
```
scatter(count(:,1),count(:,3))
```



After you brush data observations, you can perform the following operations on them:

- Delete them.
- Replace them with constant values.
- Replace them with NaN values.
- Drag or copy, and paste them to the Command Window.
- Save them as workspace variables.

For example, use the Data Brush context menu or the **Tools > Brushing > Create new variable** option to create a new variable called `count13high`.



A new variable in the workspace results:

```
count13high

count13high =
    61    186
    75    180
   114    257
```

For more information, see the MATLAB `brush` function and "Marking Up Graphs with Data Brushing" in the MATLAB Data Analysis documentation.

Linked plots, or *data linking*, is a feature closely related to data brushing. A plot is said to be linked when it has a live connection to the workspace data it depicts. The copies of variables stored in a plot object's `XData`, `YData`, (and, where appropriate, `ZData`), automatically updated whenever the workspace variables to which they are linked change or are deleted. This causes the graphs on which they appear to update automatically.

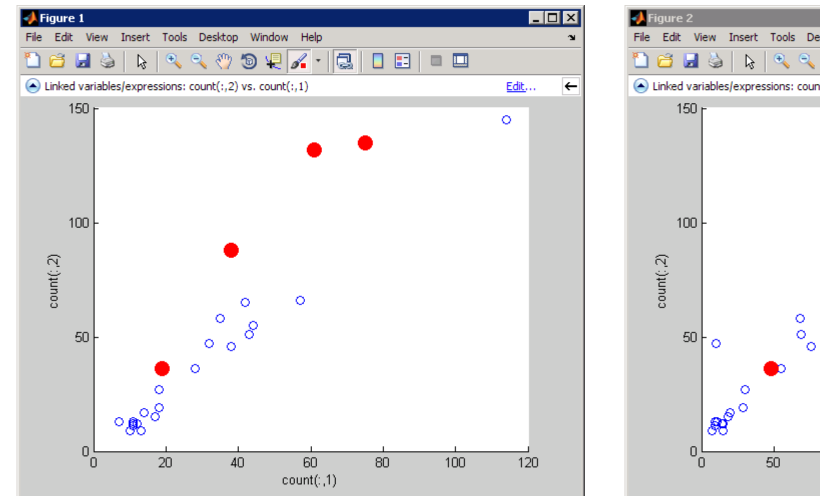
Linking plots to variables lets you track specific observations through different presentations of them. When you brush data points in linked plots,

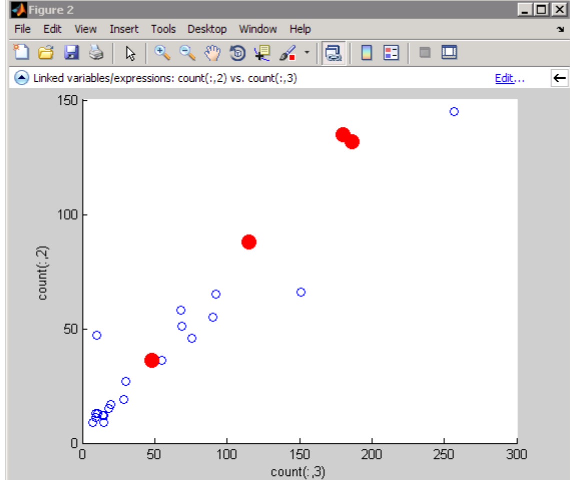
brushing one graph highlights the same observations in every graph that is linked to the same variables.

Data linking establishes immediate, two-way communication between figures and workspace variables, in the same way that the Variable Editor communicates with workspace variables. You create links by activating the Data Linking tool on a figure's toolbar. Activating this tool causes the Linked Plot information bar, displayed in the next figure, to appear at the top of the plot (possibly obscuring its title). You can dismiss the bar (shown in the following figure) without unlinking the plot; it does not print and is not saved with the figure.

The following two graphs depict scatter plot displays of linked data after brushing some observations on the left graph. The common variable, `count` carries the brush marks to the right figure. Even though the right graph is not in data brushing mode, it displays brush marks because it is linked to its variables.

```
figure
scatter(count(:,1),count(:,2))
xlabel ('count(:,1)')
ylabel ('count(:,2)')
figure
scatter(count(:,3),count(:,2))
xlabel ('count(:,3)')
ylabel ('count(:,2)')
```

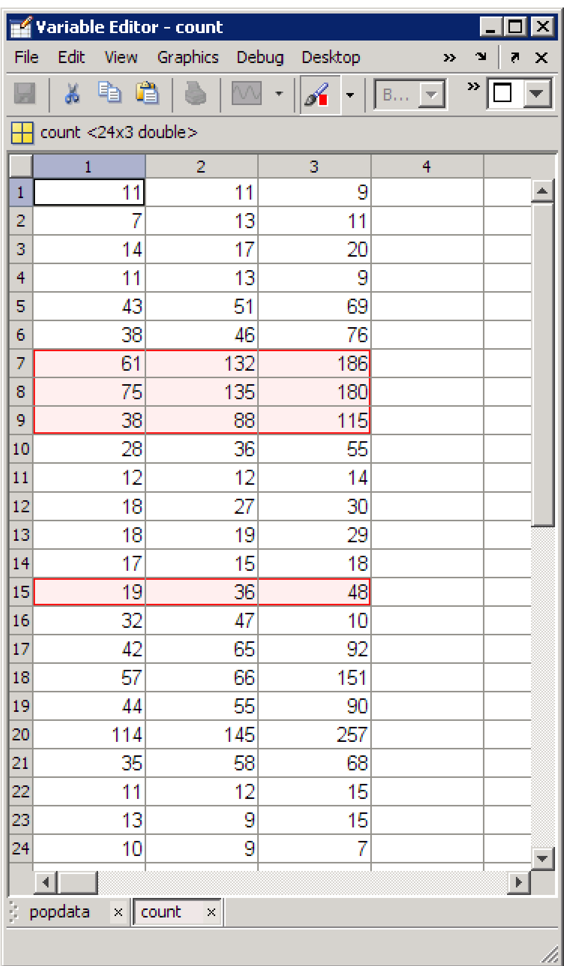




The right plot shows that the brushed observations are more linearly related than in the left plot.

Brushed data observations appear highlighted in the brushing color when you display those variables in the Variable Editor, as you can see here:

```
openvar count
```



In the Variable Editor, you can alter any values of linked plot data, and the graphs will reflect your edits. To brush data observation from the Variable Editor, click its Brushing Tool button. If the variable you brush is currently depicted in a linked plot, the observations you brush highlight in the plot as well as in the Variable Editor. When you brush a variable that is a column in a matrix, the other columns in that row are also brushed. That is, you can brush individual observations in a row or column vector, but all

columns in a matrix highlight in any row you brush, not just the observations you click.

For more information, see the `linkdata` function, "Making Graphs Responsive with Data Linking" in the MATLAB Data Analysis documentation, and "Viewing and Editing Values in the Current Workspace" in the MATLAB Desktop Environment documentation.

Modeling Data

In this section...

"Overview" on page 5-27

"Polynomial Regression" on page 5-27

"General Linear Regression" on page 5-28

Overview

Parametric models translate an understanding of data relationships into analytic tools with predictive power. Polynomial and sinusoidal models are simple choices for the up and down trends in the traffic data.

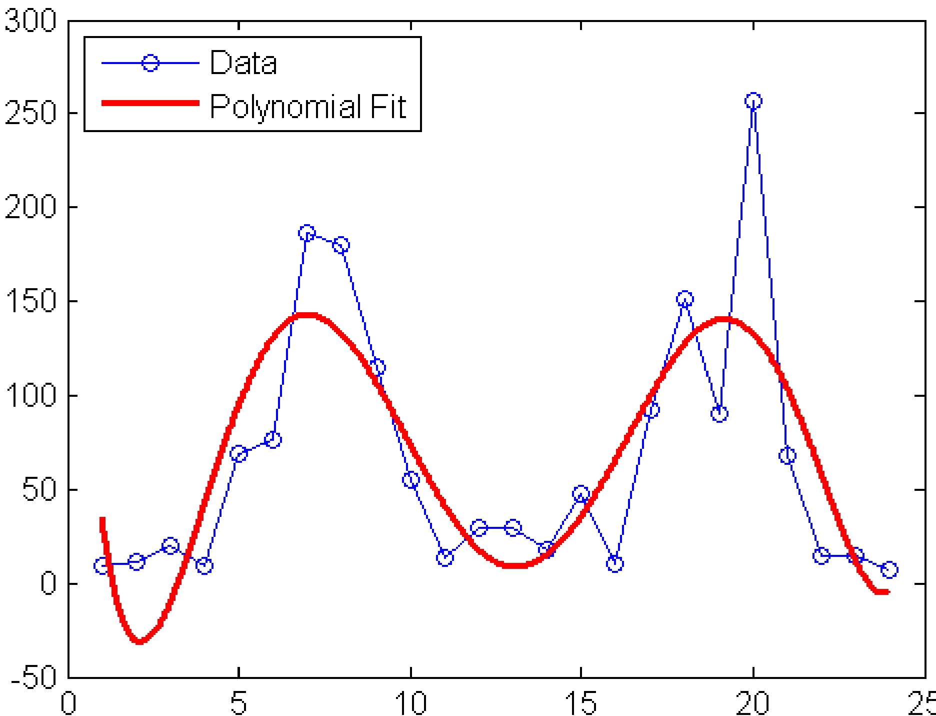
Note This section continues the data analysis from "Visualizing Data" on page 5-14.

Polynomial Regression

Use the `polyfit` function to estimate coefficients of polynomial models, then use the `polyval` function to evaluate the model at arbitrary values of the predictor.

The following code fits the traffic data at the third intersection with a polynomial model of degree six:

```
load count.dat
c3 = count(:,3); % Data at intersection 3
tdata = (1:24)';
p_coeffs = polyfit(tdata,c3,6);

figure
plot(c3,'o-')
hold on
tfit = (1:0.01:24)';
yfit = polyval(p_coeffs,tfit);
plot(tfit,yfit,'r-','LineWidth',2)
legend('Data','Polynomial Fit','Location','NW')
```



The model has the advantage of being simple while following the up-and-down trend. The accuracy of its predictive power, however, is questionable, especially at the ends of the data.

General Linear Regression

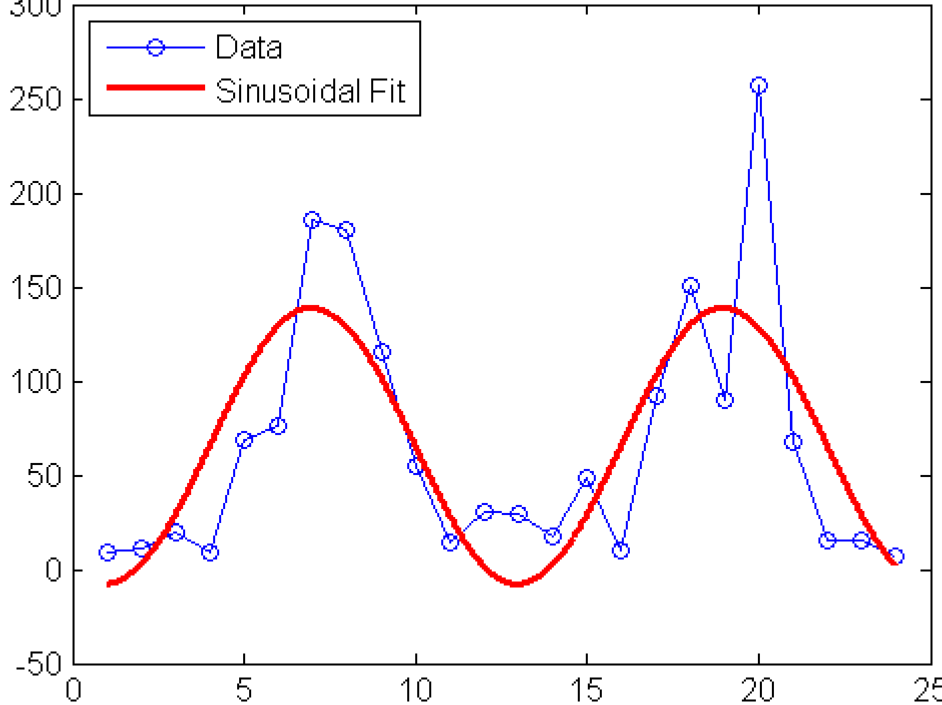
Assuming that the data are periodic with a 12-hour period and a peak around hour 7, it is reasonable to fit a sinusoidal model of the form:

$$y = a + b\cos((2\pi/12)(t-7))$$

The coefficients a and b appear linearly. Use the MATLAB `mldivide` (backslash) operator to fit general linear models:

```
load count.dat
c3 = count(:,3); % Data at intersection 3
```

```
tdata = (1:24)';
X = [ones(size(tdata)) cos((2*pi/12)*(tdata-7))];
s_coeffs = X\c3;

figure
plot(c3,'o-')
hold on
tfit = (1:0.01:24)';
yfit = [ones(size(tfit)) cos((2*pi/12)*(tfit-7))]*s_coeffs;
plot(tfit,yfit,'r-','LineWidth',2)
legend('Data','Sinusoidal Fit','Location','NW')
```



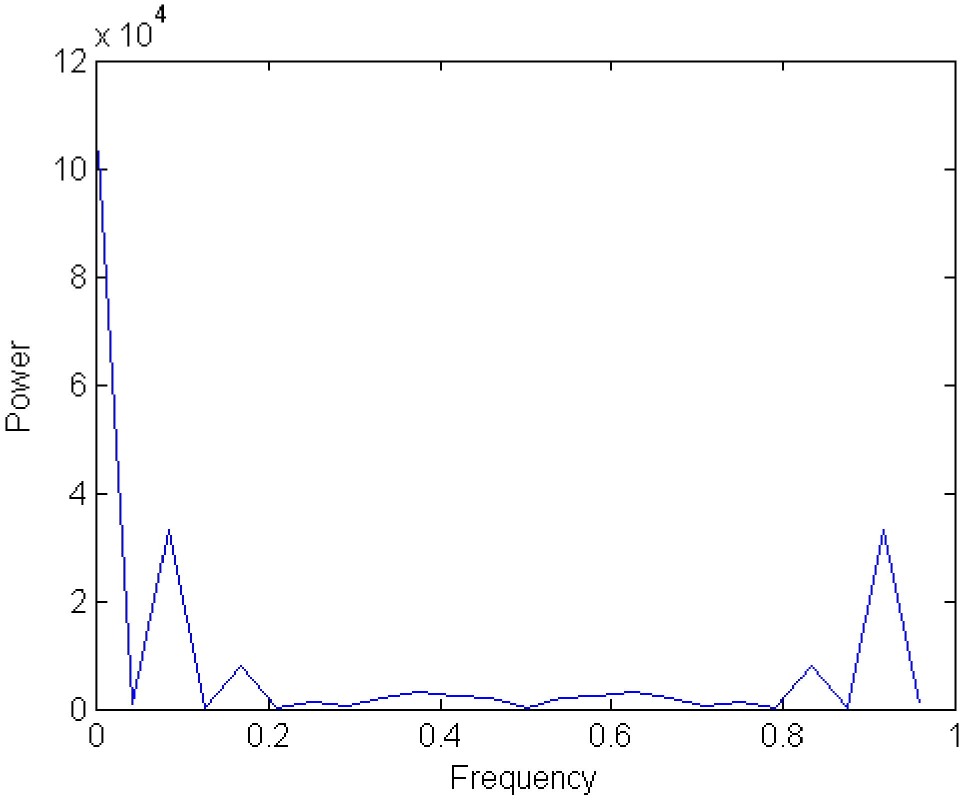
Use the `lscov` function to compute statistics on the fit, such as estimated standard errors of the coefficients and the mean squared error:

```
[s_coeffs,stdx,mse] = lscov(X,c3)
s_coeffs =
```

```
   65.5833
   73.2819
stdx =
    8.9185
   12.6127
mse =
  1.9090e+003
```

Check the assumption of a 12-hour period in the data with a *periodogram*, computed using the `fft` function:

```
Fs = 1; % Sample frequency (per hour)
n = length(c3); % Window length
Y = fft(c3); % DFT of data
f = (0:n-1)*(Fs/n); % Frequency range
P = Y.*conj(Y)/n; % Power of the DFT

figure
plot(f,P)
xlabel('Frequency')
ylabel('Power')

predicted_f = 1/12
predicted_f =
    0.0833
```



The peak near `0.0833` supports the assumption, although it occurs at a slightly higher frequency. The model can be adjusted accordingly.

See “Regression Analysis” and “Fourier Transforms” in the MATLAB Data Analysis and Mathematics documentation for more information on data modeling.

Creating Graphical User Interfaces

- "What Is GUIDE?" on page 6-2
- "Laying Out a GUI" on page 6-3
- "Programming a GUI" on page 6-7

What Is GUIDE?

GUIDE, the MATLAB graphical user interface development environment, provides a set of tools for creating graphical user interfaces (GUIs). These tools greatly simplify the process of designing and building GUIs. You can use the GUIDE tools to perform the following tasks:

- Lay out the GUI.

  Using the GUIDE Layout Editor, you can lay out a GUI easily by clicking and dragging GUI components—such as panels, buttons, text fields, sliders, menus, and so on—into the layout area. GUIDE stores the GUI layout in a FIG-file.

- Program the GUI.

  GUIDE automatically generates an M-file that controls how the GUI operates. The M-file initializes the GUI and contains a framework for the most commonly used callbacks for each component—the commands that execute when a user clicks a GUI component. Using the M-file editor, you can add code to the callbacks to perform the functions you want.

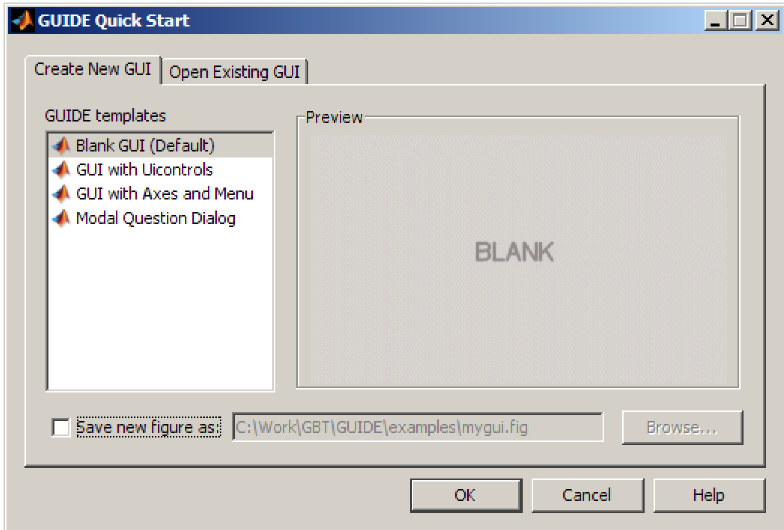
Note You can also create GUIs programmatically. For information on how to get started, see "Creating a Simple GUI Programmatically" in the MATLAB Creating Graphical User interfaces documentation.

Laying Out a GUI

In this section...
"Starting GUIDE" on page 6-3
"The Layout Editor" on page 6-4

Starting GUIDE

Start GUIDE by typing `guide` at the MATLAB command prompt. This command displays the GUIDE Quick Start dialog box, as shown in the following figure.

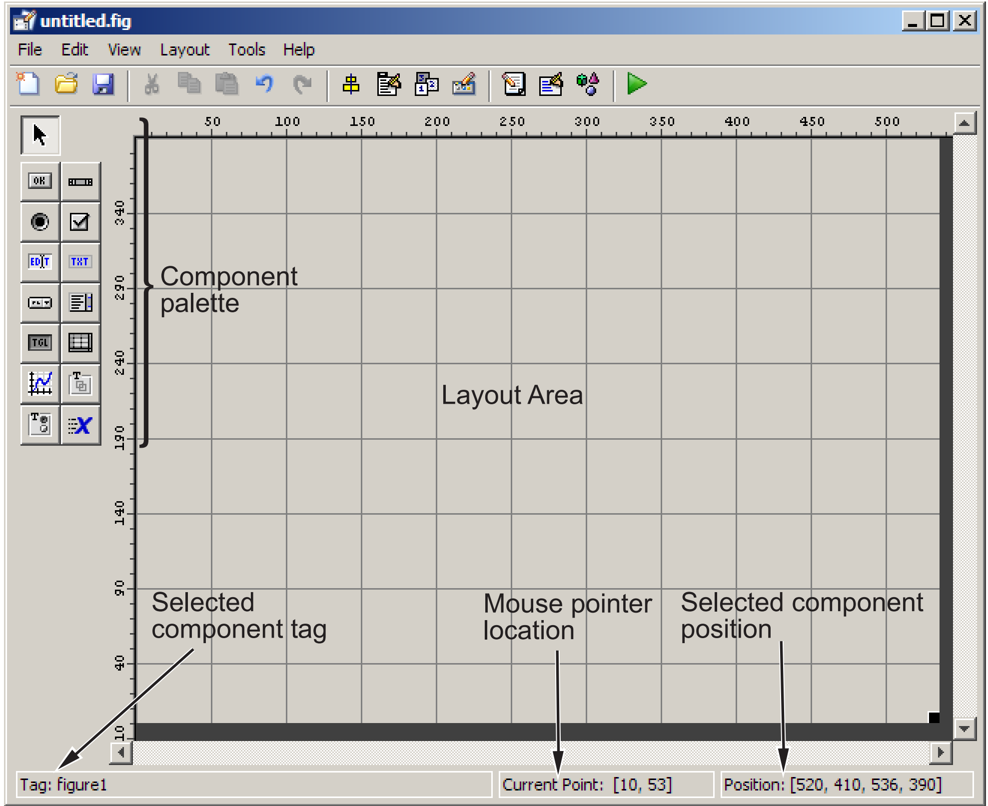


From the GUIDE Quick Start dialog box, you can perform the following tasks:

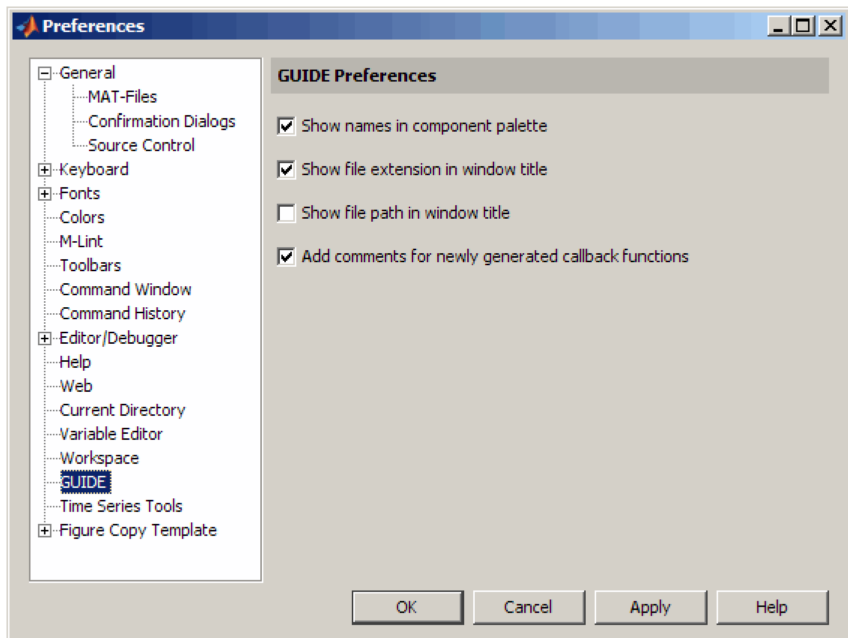
- Create a new GUI from one of the GUIDE templates—prebuilt GUIs that you can modify for your own purposes.
- Open an existing GUI.

The Layout Editor

When you open a GUI in GUIDE, it is displayed in the Layout Editor, which is the control panel for all of the GUIDE tools. The following figure shows the Layout Editor with a blank GUI template.

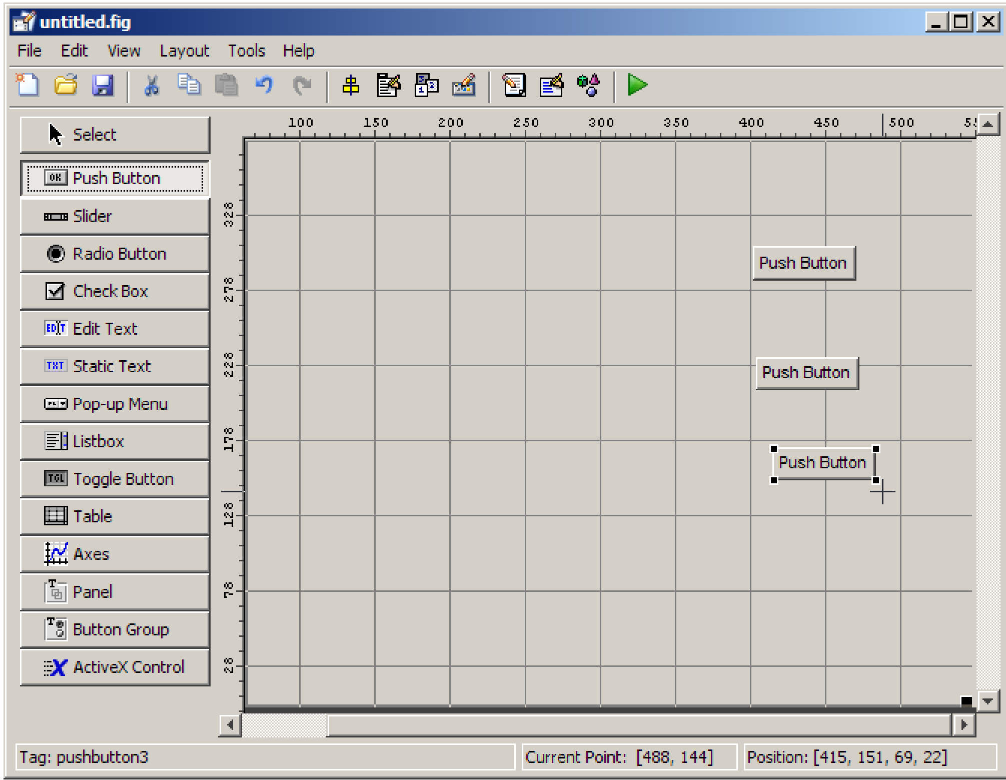


You can expand the tool icons in the Layout Editor to include component names. Open **File > Preferences** from GUIDE or the MATLAB Desktop and select **Show Names in Component Palette**, as shown in the following illustration.



See "GUIDE Preferences" in the MATLAB Creating Graphical Interfaces documentation for details.

You can lay out your GUI by dragging components, such as panels, push buttons, pop-up menus, or axes, from the component palette, at the left side of the Layout Editor, into the layout area. For example, if you drag three push buttons into the layout area, it might look like this.



The illustration also shows how the GUIDE tool palette looks when you set a preference to show component names, as described above.

You can also use the Layout Editor (along with the Toolbar Editor and Icon Editor) to create menus and toolbars, create and modify tool icons, and set basic properties of the GUI components.

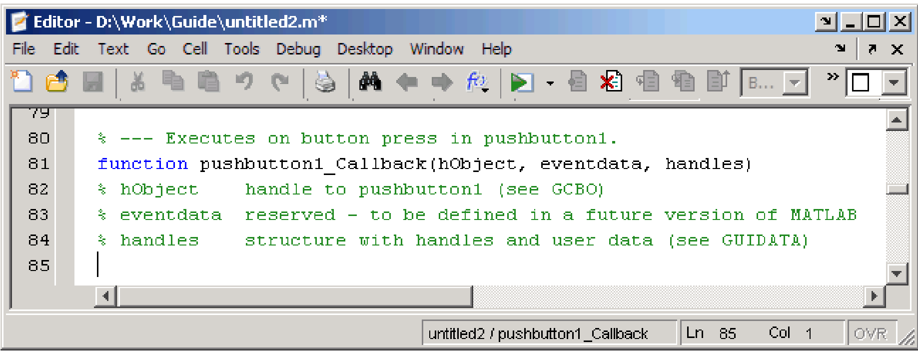
To get started using the Layout Editor and setting property values, see "Creating a Simple GUI with GUIDE" in the MATLAB Creating Graphical User Interfaces documentation. "Examples of GUIDE GUIs" in the same documentation illustrates the variety of GUIs that you can create with GUIDE.

Programming a GUI

After laying out the GUI and setting component properties, the next step is to program the GUI. You program the GUI by coding one or more callbacks for each of its components. *Callbacks* are functions that execute in response to some action by the user. A typical action is clicking a push button.

A GUI's callbacks are found in an M-file that GUIDE generates automatically. GUIDE adds templates for the most commonly used callbacks to this M-file, but you may want to add others. Use the M-file Editor to edit this file.

The following figure shows the Callback template for a push button.



To learn more about programming a GUI, see "Creating a Simple GUI with GUIDE" in the MATLAB Creating Graphical User Interfaces documentation.

7

Desktop Tools and Development Environment

If you have an active Internet connection, you can watch the Working in The Development Environment video demo for an overview of the major functionality.

- "Desktop Overview" on page 7-2
- "Command Window and Command History" on page 7-5
- "Getting Help" on page 7-7
- "Workspace Browser and Variable Editor" on page 7-19
- "Managing Files in MATLAB" on page 7-21
- "Finding and Getting Files Created by Other Users — File Exchange" on page 7-25
- "Editor" on page 7-27
- "Improving and Tuning M-Files" on page 7-33

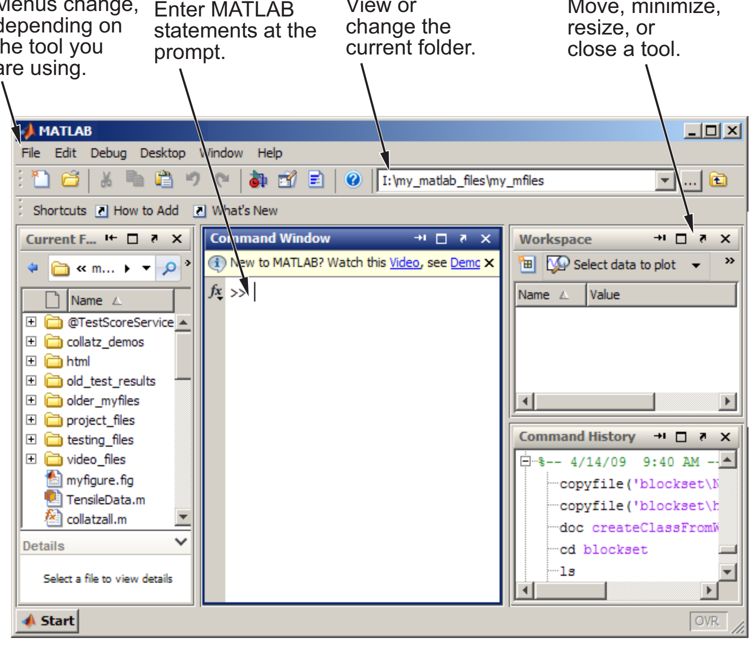
Desktop Overview

In this section...
"Introduction to the Desktop" on page 7-2
"Arranging the Desktop" on page 7-3
"Start Button" on page 7-3

Introduction to the Desktop

Use desktop tools to manage your work and become more productive using MATLAB software. You can also use MATLAB functions to perform the equivalent of most of the features found in the desktop tools.

The following illustration shows the default configuration of the MATLAB desktop. You can modify the setup to meet your needs.



For More Information For an overview of the desktop, watch the Working in the Development Environment video demo. For complete details, see the MATLAB Desktop Tools and Development Environment documentation.

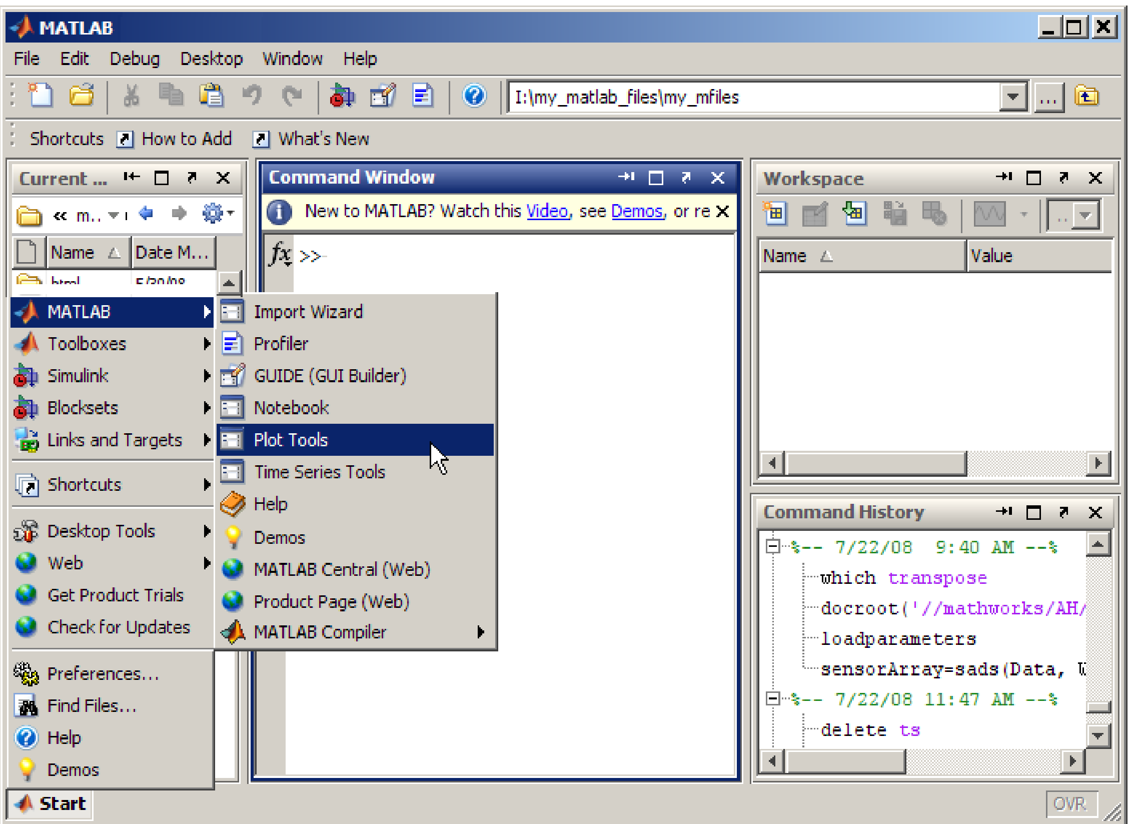
Arranging the Desktop

These are some common ways to customize the desktop:

- Show or hide desktop tools via the **Desktop** menu.
- Resize any tool by dragging one of its edges.
- Move a tool outside of the desktop by clicking the undock button in the tool's title bar.
- Reposition a tool within the desktop by dragging its title bar to the new location. Tools can occupy the same position, as shown for the Current Folder and Workspace browser in the preceding illustration. When they do, you access a tool by clicking its title bar.
- Maximize or minimize (temporarily hide) a tool within the desktop via the **Desktop** menu.
- Change fonts, customize the toolbar, and access other options by using **File > Preferences**.

Start Button

The MATLAB **Start** button provides easy access to tools, demos, shortcuts, and documentation. Click the **Start** button to see the options.



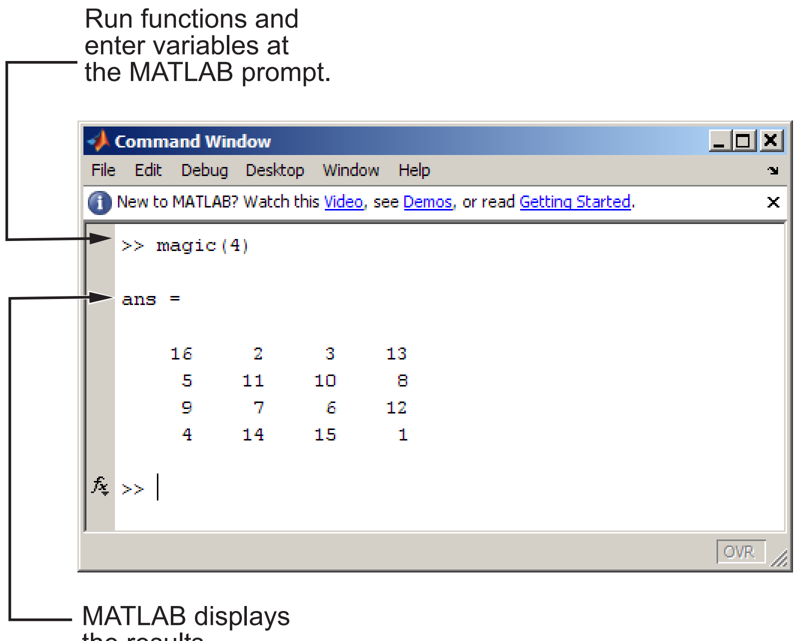
For More Information See “Desktop” in the MATLAB Desktop Tools and Development Environment documentation.

Command Window and Command History

In this section...
"Command Window" on page 7-5 "Command History" on page 7-6

Command Window

Use the Command Window to enter variables and to run functions and M-file scripts.



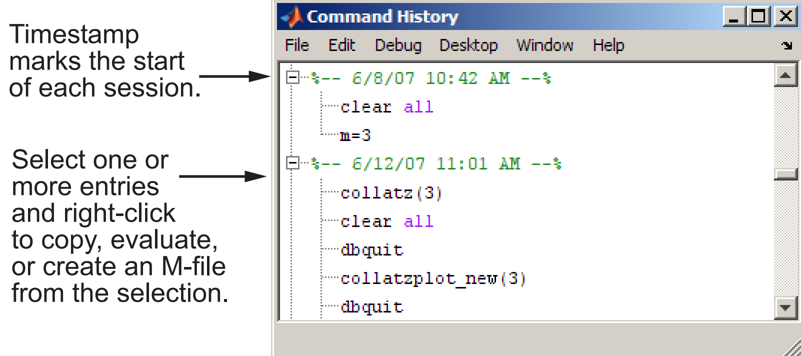
Press the up arrow key ↑ to recall a statement you previously typed. Edit the statement as needed, and then press **Enter** to run it. For more information about entering statements in the Command Window, see "Controlling Command Window Input and Output" on page 2-30.

There are other tools available to help you remember functions and their syntax, and to enter statements correctly. For example, to look for functions, use the Function Browser to look for functions—click the f_x button at the left of the prompt to open the tool. For more information on ways to get help while you work in the Command Window, see "Assistance While Entering Statements".

For More Information See "Running Functions — Command Window and History" in the MATLAB Desktop Tools and Development Environment documentation for complete details.

Command History

Statements you enter in the Command Window are logged in the Command History. From the Command History, you can view and search for previously run statements, as well as copy and execute selected statements. You can also create an M-file from selected statements.



To save the input and output from a MATLAB session to a file, use the `diary` function.

For More Information See "Using the Command History Window" in the MATLAB Desktop Tools and Development Environment documentation, and the reference page for the `diary` function.

Getting Help

In this section...
"Ways to Get Help" on page 7-7
"Using the Help Browser to Access Documentation, Examples, and Demos" on page 7-8

Ways to Get Help

To...	Try This	More Information
Look for getting started guides, code examples, demos, and more.	In the Help browser contents pane, expand the listing for a product.	"Browsing for Documentation and Demos" on page 7-13
Find information about any topic.	In the Help browser search field, type words you want to find in the documentation. Then press **Enter**.	"Searching for Documentation and Demos" on page 7-10
Find a function and get help for it in a temporary window.	Select **Help > Function Browser**, then search or browse.	"Finding Functions Using the Function Browser"
Get syntax and function hints while using the Command Window and Editor.	Use colors and other cues to determine correct syntax. While entering a function, pause after typing the left parenthesis. A summary of syntax options displays in a temporary window.	"Assistance While Entering Statements"

To...	Try This	More Information
View help for a function or block.	Run `doc` *`name`* to display the reference page in the Help browser. For quick help in the Command Window, run `help` *`name`*. Sometimes, the `help` text shows *`name`* in all uppercase letters to distinguish it. When you use *`name`*, do not use all uppercase letters.	`doc` reference page `help` reference page
Get specific help while using a tool.	Use the context-sensitive help, which some tools provide. Access the help using standard methods, such as **Help** buttons and context menus.	See the documentation for a tool to learn about any special context-sensitive help available.
Check code for problems and get recommendations to maximize performance and maintainability.	In the Editor, view M-Lint messages.	"Checking M-File Code for Problems Using the M-Lint Code Analyzer"

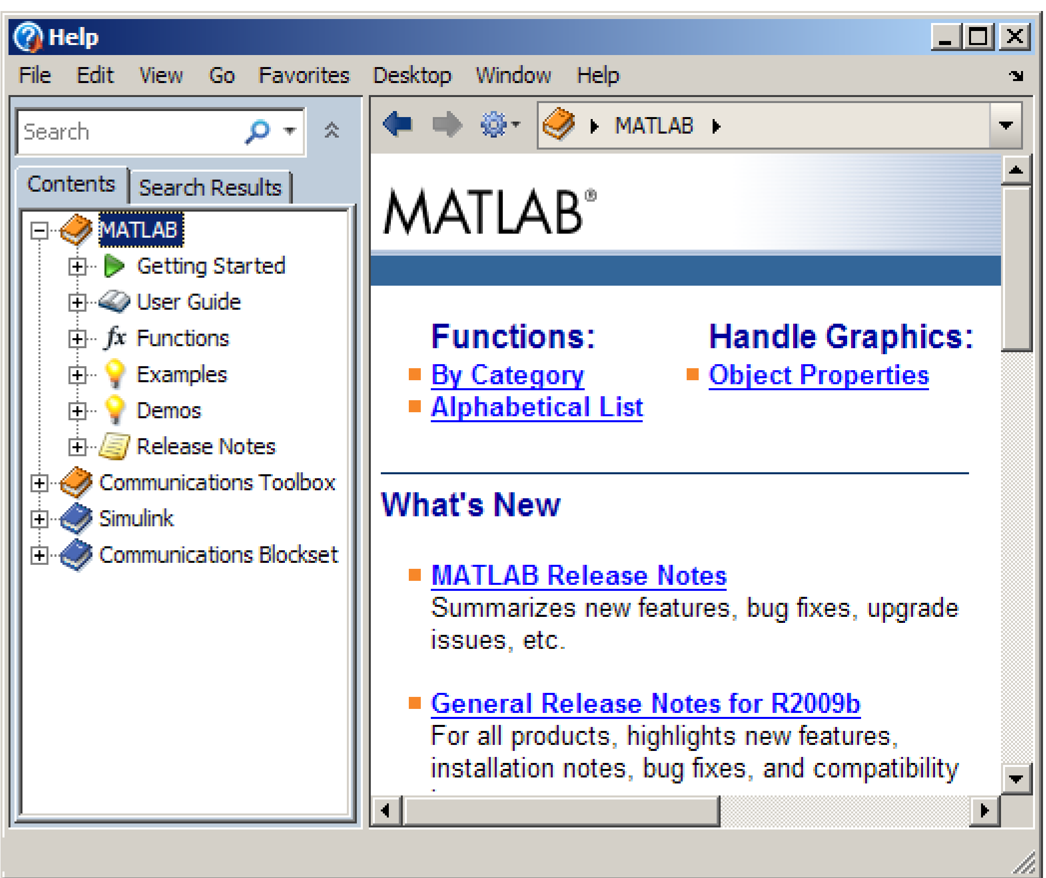
Using the Help Browser to Access Documentation, Examples, and Demos

- "Types of Information in the Help Browser" on page 7-10
- "Searching for Documentation and Demos" on page 7-10
- "Browsing for Documentation and Demos" on page 7-13
- "Running Demos and Code in Examples" on page 7-15

To open the Help browser, from any desktop tool, select **Help > Product Help**.

The Help browser shows **Contents** and **Search Results** in the left pane. When you select an item in the left pane, the right pane displays that page of documentation or that demo.

Use the Help browser to find and view documentation and demos for all installed MathWorks products. To use documentation and demos for only some of the installed products, see “Filter by Product — Specifying Products Used in the Help Browser”.



Types of Information in the Help Browser

Icon	Type	Description
	Getting Started guide	Introduction and overview of a topic. Intended for first time use or a quick reminder of basics.
	User guide	Details and advanced topics about a tool or product.
	Reference page for block	Detailed description of a block, and links to related topics.
	Reference page for function	Syntax, description, short examples, and links to related topics.
	Examples	Runnable code examples and tutorials in the documentation.
	Demos	Runnable code, models, and video demonstrations of product features.
	Release Notes	New features, compatibility considerations, and bug reports for recent versions of products.

Searching for Documentation and Demos

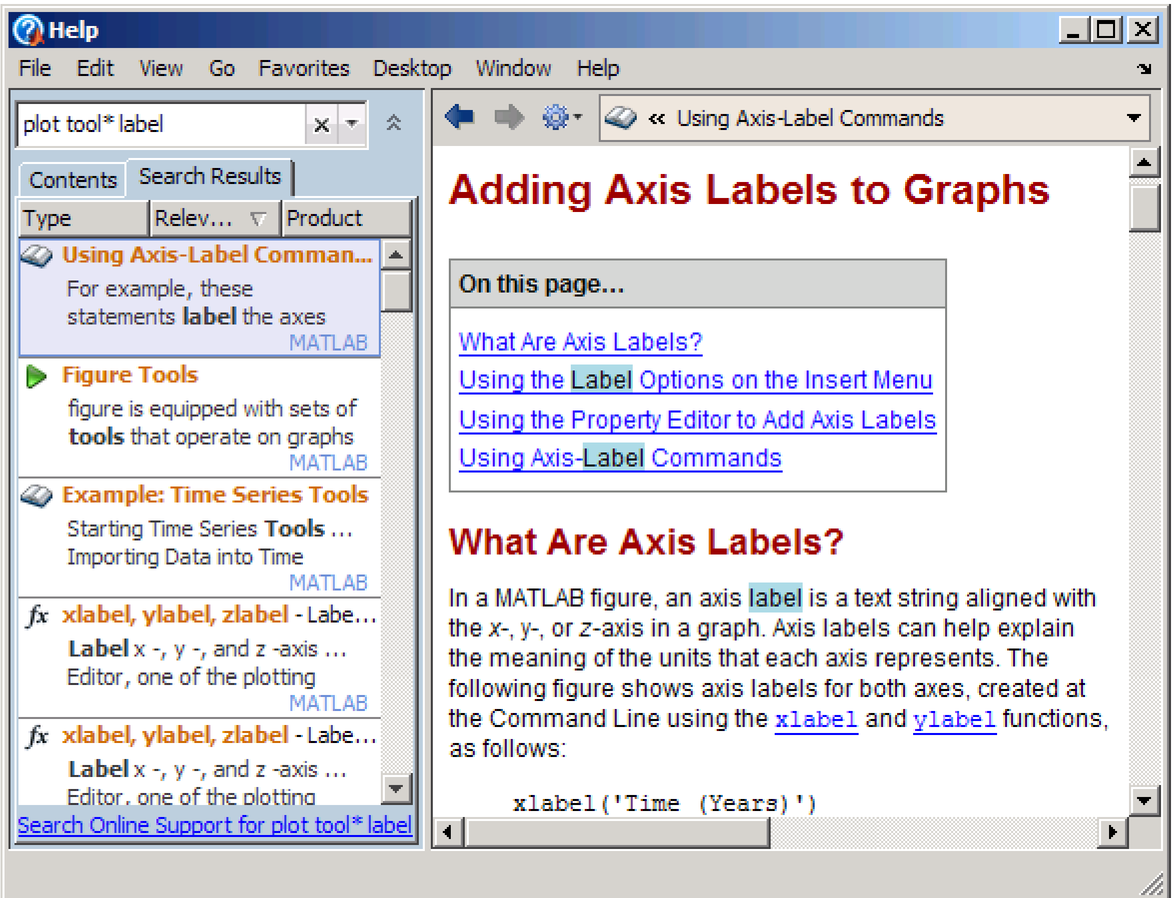
1 In the Help browser **Search** field, enter the words you want to find. Search finds pages containing all the words, unless you use any of the syntax options described in the following table.

Option	Syntax	Example
Exact phrase	`" "` (quotation marks)	`"word1 word2"`
Wildcards in place of characters, for partial word searching	`*`	`word*`
Some of the words	`OR`	`word1 OR word2`
Exclude words	`NOT`	`word1 NOT word2`

For example, enter `plot tool* label`.

2 Press **Enter**.

Results appear in the **Search Results** pane. An icon indicates the type of result. See "Types of Information in the Help Browser" on page 7-10.



3 Arrange results:

- The default sort order is by relevance. Change the order by clicking the column header for **Type** or **Product**.
- For results sorted by **Type** or **Product**, you can collapse and expand results for each type or product group. To expand or collapse all groups,

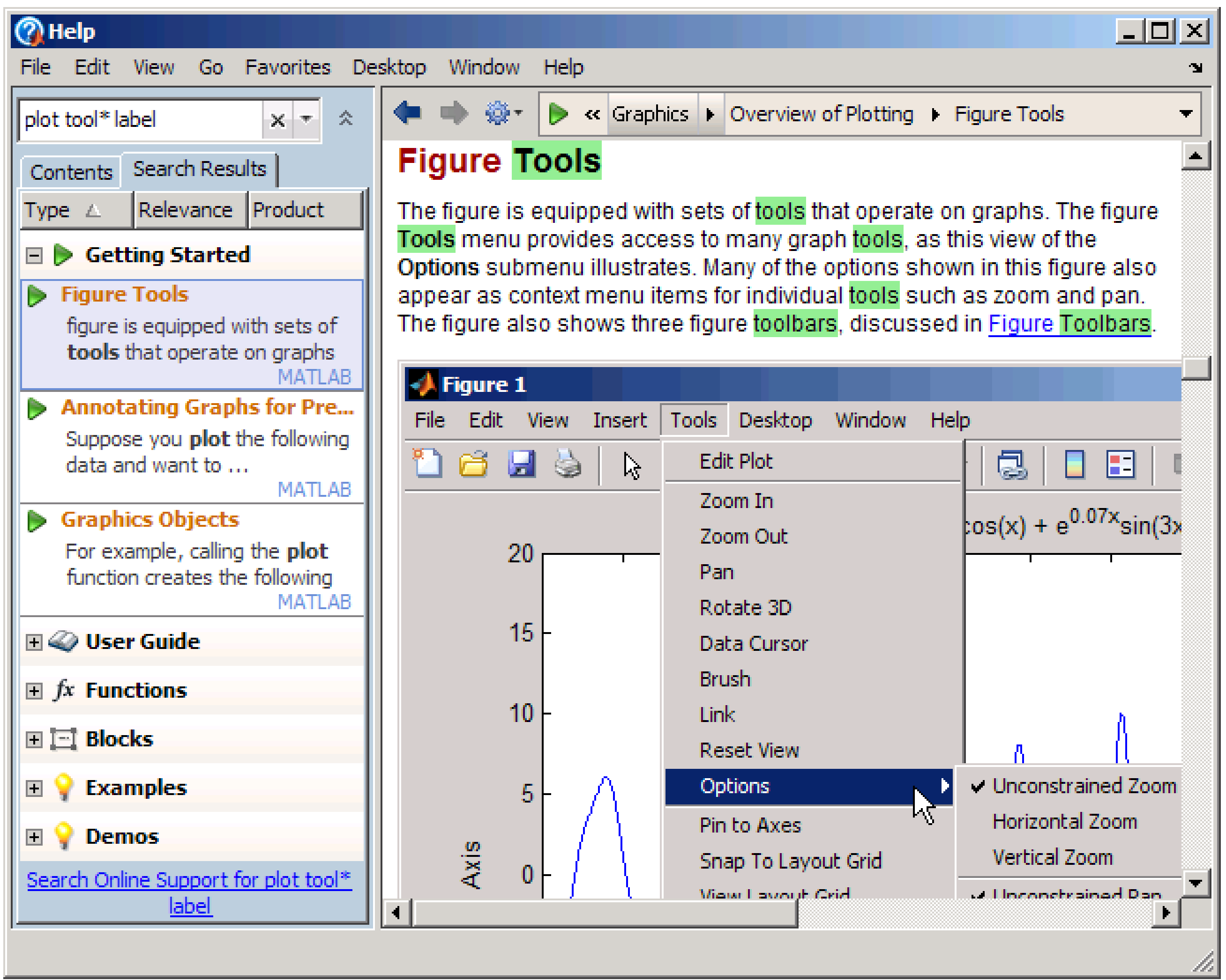
right-click in the results pane, and select the option you want from the context menu.

For example, to focus on introductory material, do the following. Click the **Type** column header. Right-click and select **Collapse All**. Then expand the **Getting Started** group.

4 Select a result to view the page.

- The Help browser highlights the search words on the page. To clear highlights, select **Refresh** from the Actions button .
- To see where the page is within the documentation contents, use the navigation bar at the top of the page.

  Or click the **Contents** tab.



See also “Getting Better Search Results”.

Browsing for Documentation and Demos

You can find information by looking at a hierarchical view of documentation and demos.

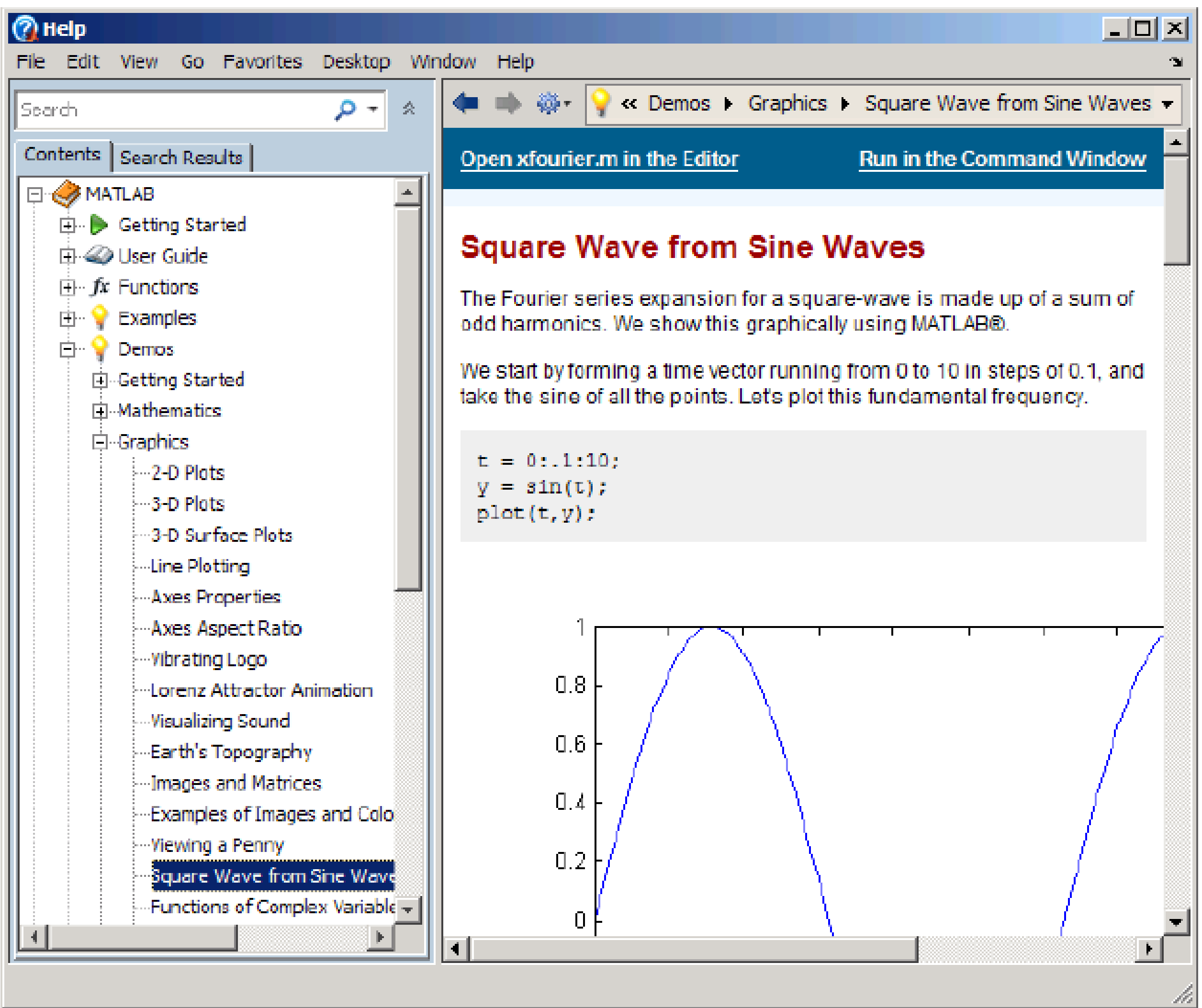
1 In the Help browser, click the **Contents** tab.

2 View the types of information available for a product by expanding the product in the **Contents** listing. For example, expand `MATLAB` by clicking **+**.

3 View available topics within a type by expanding the type for a product. For example, select `MATLAB > Demos > Graphics`.

   - Expand one topic by clicking +. Or select the topic and press the right arrow key.
   - Expand all topics within the selected topic by pressing the ***** key on the numeric keypad.

4 To view an item in the display pane, select it. For example, select `MATLAB > Demos > Graphics > Square Wave from Sine Waves`.



Running Demos and Code in Examples

- "Review Workspace Before Running Demos and Code in Examples" on page 7-16
- "Running an M-File Demo" on page 7-16

• "Running Code That Is in Documentation or a Demo" on page 7-17

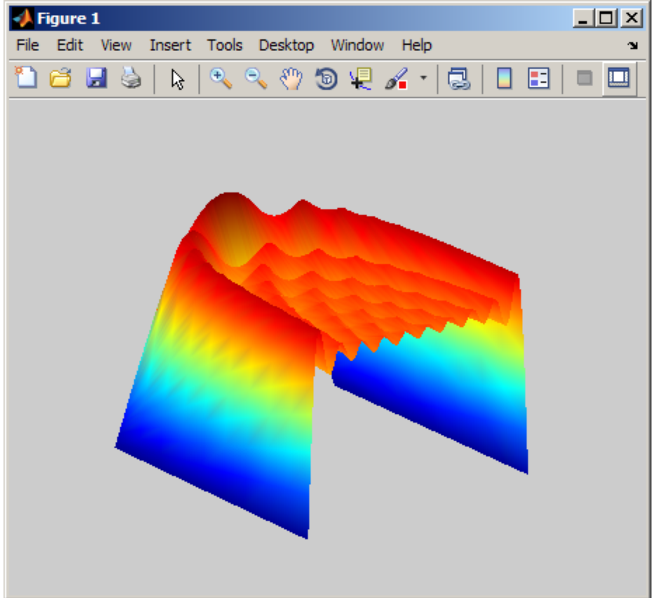
Review Workspace Before Running Demos and Code in Examples. M-file demos and some code in examples run as scripts. Scripts store variables in the base workspace. There could be name conflicts if you have variables in the base workspace and the demo or code creates a variable with the same name. For example, the demo could overwrite your data. Compare the base workspace to a demo or code example before you run it, and address any name conflicts.

Running an M-File Demo. For an M-file demo displayed in the Help browser:

1. Click **Open *`filename`* in Editor**. For example, with the `MATLAB > Demos > Graphics > Square from Sine Waves` demo displayed, click **Open xfourier.m in the Editor**. `xfourier.m` is the name of the demo file.

2. With the file open in the Editor, click Run.

The following figure illustrates the results of running the `MATLAB > Demos > Graphics > Square Wave from Sine Waves` demo.



Running Code That Is in Documentation or a Demo. When the displayed documentation page or demo contains code, you can select some or all of the code and run it:

1. Prepare variables the code uses, if necessary to run a selection of code.
2. Select the code.
3. Right-click and select **Evaluate Selection**.

To view the contents of a variable, right-click the variable and select **Open Selection**.

Code in the documentation includes small fragments, as well as complete executable example files. The documentation example files are in `matlabroot/help/.../examples` for each product. The files in `examples` are not on the search path. When the documentation instructs you to run an example file, first make the file accessible to MATLAB in one of these ways:

- Change the current folder to the folder containing the example file.

- Add to the search path the folder containing the example file.
- Copy the example file to another location that MATLAB can access.

For More Information There are additional options for getting help. See "Help, Demos, and Related Resources".

Workspace Browser and Variable Editor

In this section...

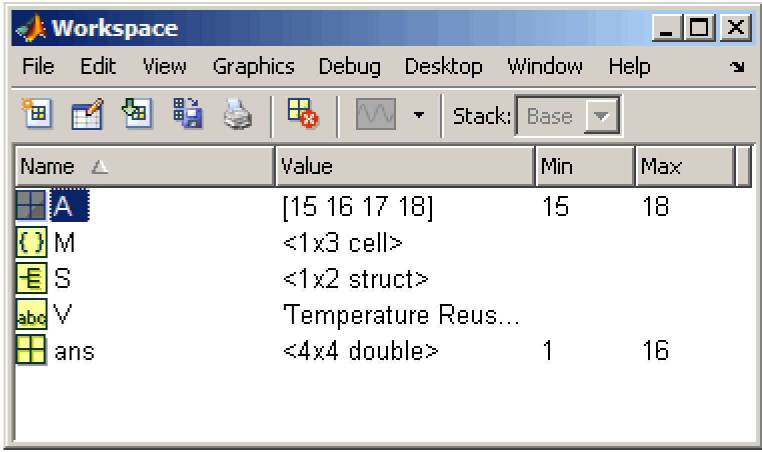
"Workspace Browser" on page 7-19

"Variable Editor" on page 7-20

Workspace Browser

The MATLAB workspace consists of the set of variables built up during a MATLAB session and stored in memory. You add variables to the workspace by using functions, running M-files, and loading saved workspaces.

To view the workspace and information about each variable, use the Workspace browser, or use the functions `who` and `whos`.



To delete variables from the workspace, select the variables, and then select **Edit > Delete**. Alternatively, use the `clearvars` or `clear` functions.

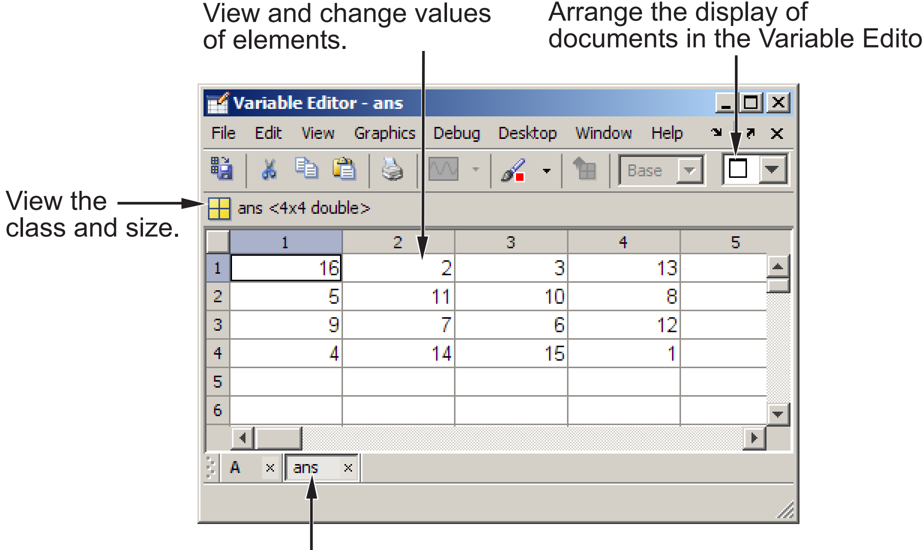
The workspace does not persist after you end the MATLAB session. To save the workspace to a file that can be read during a later MATLAB session, select **File > Save**, or use the `save` function. Saving preserves the workspace in a binary file called a MAT-file, which has a `.mat` extension. You can use options

to save to different formats. To read in a MAT-file, select **File > Import Data**, or use the `load` function.

For More Information See "MATLAB Workspace" in the MATLAB Desktop Tools and Development Environment documentation and the reference pages for the `who`, `clear`, `save`, and `load` functions.

Variable Editor

Double-click a variable in the Workspace browser, or use `openvar variablename`, to see it in the Variable Editor. Use the Variable Editor to view and edit a visual representation of variables in the workspace.



For More Information See "Viewing and Editing Workspace Variables with the Variable Editor" in the MATLAB Desktop Tools and Development Environment documentation and the reference page for the `openvar` function.

Managing Files in MATLAB

In this section...

"How MATLAB Helps You Manage Files" on page 7-21

"Making Files Accessible to MATLAB" on page 7-21

"Using the Current Folder Browser to Manage Files" on page 7-22

"More Ways to Manage Files" on page 7-24

How MATLAB Helps You Manage Files

MATLAB provides tools and functions to help you:

- Find a file you want to view, change, or run
- Organize your files
- Ensure MATLAB can access a file so you can run or load it

Making Files Accessible to MATLAB

MATLAB limits where it looks for files so it can locate them more quickly. To run or get help for an M-file, or to load a MAT-file, the file must be in one of these locations:

- MATLAB current folder
- A folder that is on the MATLAB search path

Similarly, files called by files you run also must be in one of these locations.

Special cases are:

- Private, class, and package folders
- When there are multiple files with the same name accessible to MATLAB

By default, files provided with MathWorks products are in folders on the search path. You do not have to do anything for MATLAB to access the files. These files are in `matlabroot/toolbox`. To determine the location of *`matlabroot`*, run the `matlabroot` function.

By default, the search path also includes a folder named `MATLAB` where you can store files that you and other users create. To determine the location of the `MATLAB` folder, run the `userpath` function.

To access files in any other location, either:

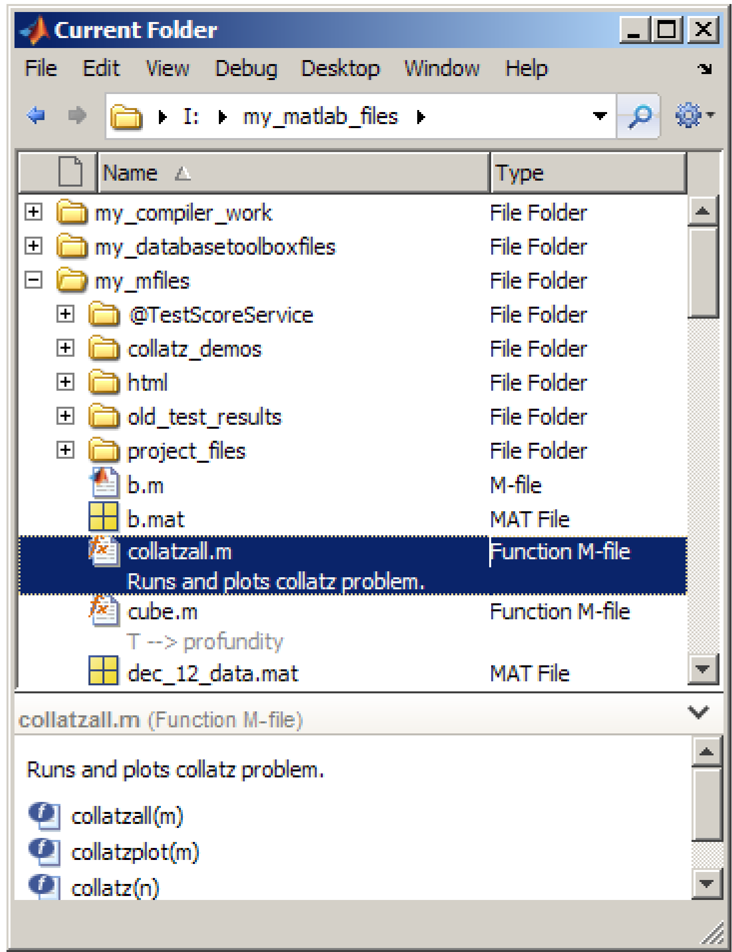
- Make the folder containing the files be the current folder
- Add the folders containing the files to the search path.

Note Do not store files under *`matlabroot`*`/toolbox`, or you could experience problems.

Using the Current Folder Browser to Manage Files

The Current Folder browser is a key tool for managing files.

Open the Current Folder browser by selecting **Desktop > Current Folder** from the MATLAB desktop.



Use the Current Folder browser to:

- See the contents of the current folder.
- View and change the current folder using the address bar.
- Find files and folders using the search tool .
- Arrange information about files and folders using the **View** menu.
- Change files and folders, such as renaming or moving them.

- Run, open, get help for, and perform other actions on the selected file or folder by right-clicking and using the context menu.

More Ways to Manage Files

- Change the search path using the Set Path dialog box. To open it, select **File > Set Path**.
- Find files and content within files across multiple folders using the Find Files tool. To open the tool, select **Edit > Find Files**.
- View and change the current folder using the Current Folder field in the desktop toolbar.
- Manage files programmatically using functions. See the function category, “Workspace, Search Path, and File Operations”.

For More Information See “Managing Files in MATLAB” in the MATLAB Desktop Tools and Development Environment documentation

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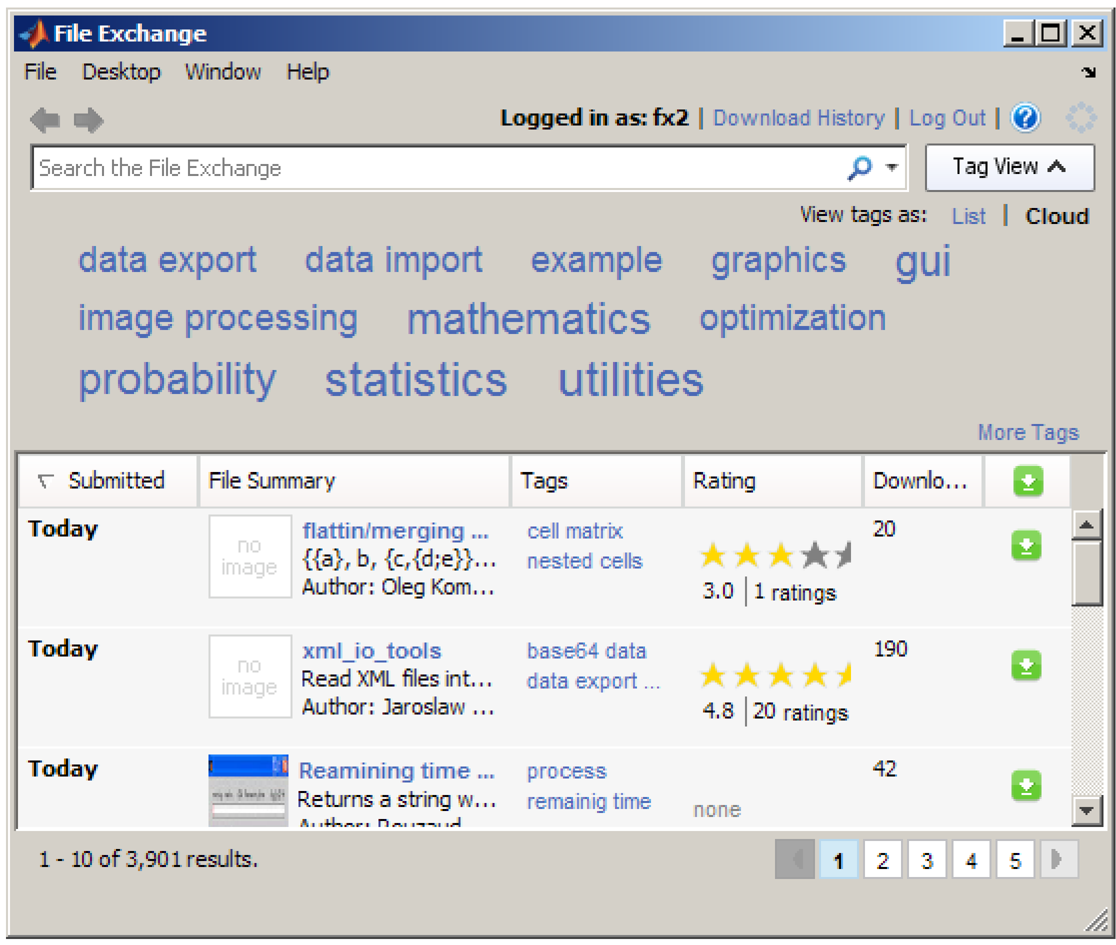
Finding and Getting Files Created by Other Users — File Exchange

Use files created by other MATLAB users to save you time and provide you with new ideas for your own work.

Users who want to share their files submit them to the File Exchange repository at The MathWorks Web site.

You can then:

- Access the repository using the File Exchange desktop tool.
- Log in using your MathWorks Account.
- Use the tool to find, view details about, and download files to use.



For an overview, watch this video: Accessing the File Exchange from the MATLAB Desktop.

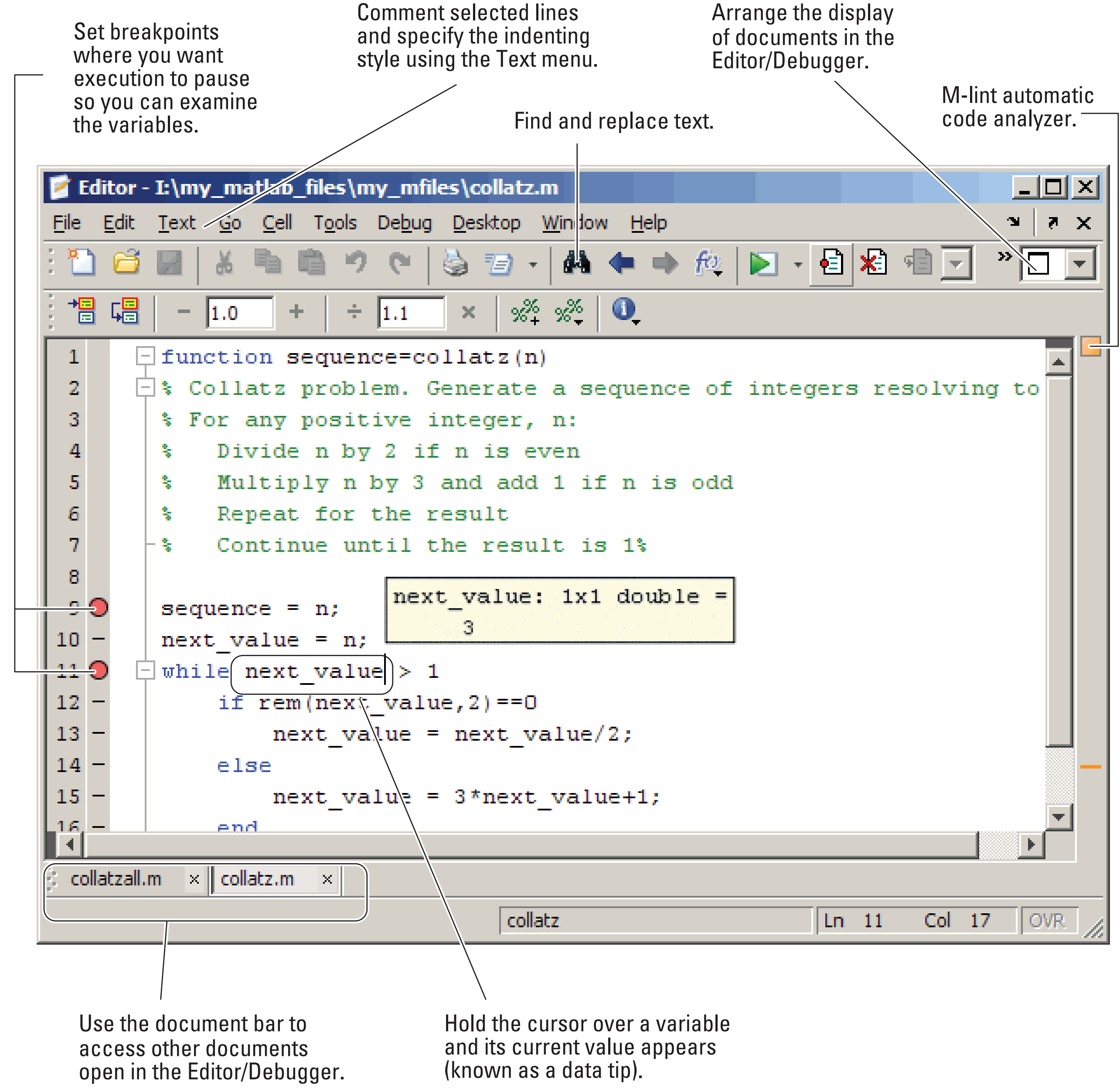
For More Information See "File Exchange — Finding and Getting Files Created by Other Users" in the MATLAB Desktop Tools and Development Environment documentation.

Editor

In this section...
“Editing M-Files” on page 7-27
“Publishing M-Files” on page 7-29

Editing M-Files

Use the Editor to create and debug M-files, which are programs you write to run MATLAB functions. The Editor provides a graphical user interface for text editing, as well as for M-file debugging. To create or edit an M-file use **File > New** or **File > Open**, or use the `edit` function.


Set breakpoints where you want execution to pause so you can examine the variables.
Comment selected lines and specify the indenting style using the Text menu.
Arrange the display of documents in the Editor/Debugger.
Find and replace text.
M-lint automatic code analyzer.
Editor - I:\my_matlab_files\my_mfiles\collatz.m
File Edit Text Go Cell Tools Debug Desktop Window Help
1.0
1.1
function sequence=collatz(n)
% Collatz problem. Generate a sequence of integers resolving to
% For any positive integer, n:
% Divide n by 2 if n is even
% Multiply n by 3 and add 1 if n is odd
% Repeat for the result
% Continue until the result is 1%
sequence = n;
next_value = n;
next_value: 1x1 double =
3
while next_value > 1
if rem(next_value,2)==0
next_value = next_value/2;
else
next_value = 3*next_value+1;
end
collatzall.m
collatz.m
collatz
Ln 11
Col 17
OVR
Use the document bar to access other documents open in the Editor/Debugger.
Hold the cursor over a variable and its current value appears (known as a data tip).

You can use any text editor to create M-files, such as Emacs. Use Editor/Debugger preferences (accessible from the desktop by selecting **File > Preferences > Editor/Debugger**) to specify that editor as the default. If you use another editor, you can still use the MATLAB Editor for debugging, or you can use debugging functions, such as `dbstop`, which sets a breakpoint.

If you just need to view the contents of an M-file, you can display the contents in the Command Window using the `type` function.

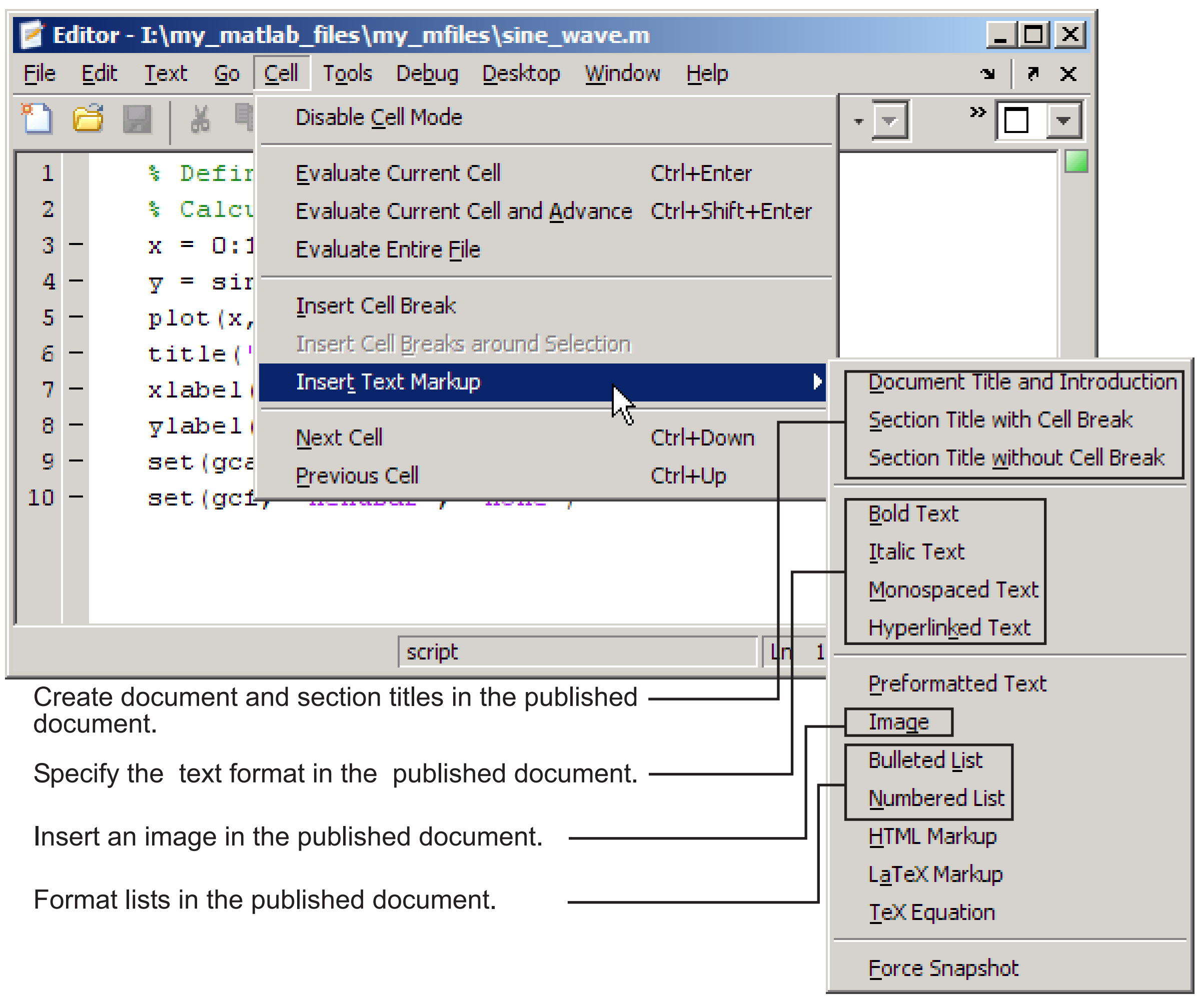
Use the M-Lint automatic code analyzer to help you identify problems and potential improvements in your code. For details, see "Improving and Tuning M-Files" on page 7-33.

You can evaluate your code in sections, called cells, and can publish your code, including results, to popular output formats like HTML. For more information, see "Using Cells for Rapid Code Iteration and Publishing Results" in the MATLAB Desktop Tools and Development Environment documentation.

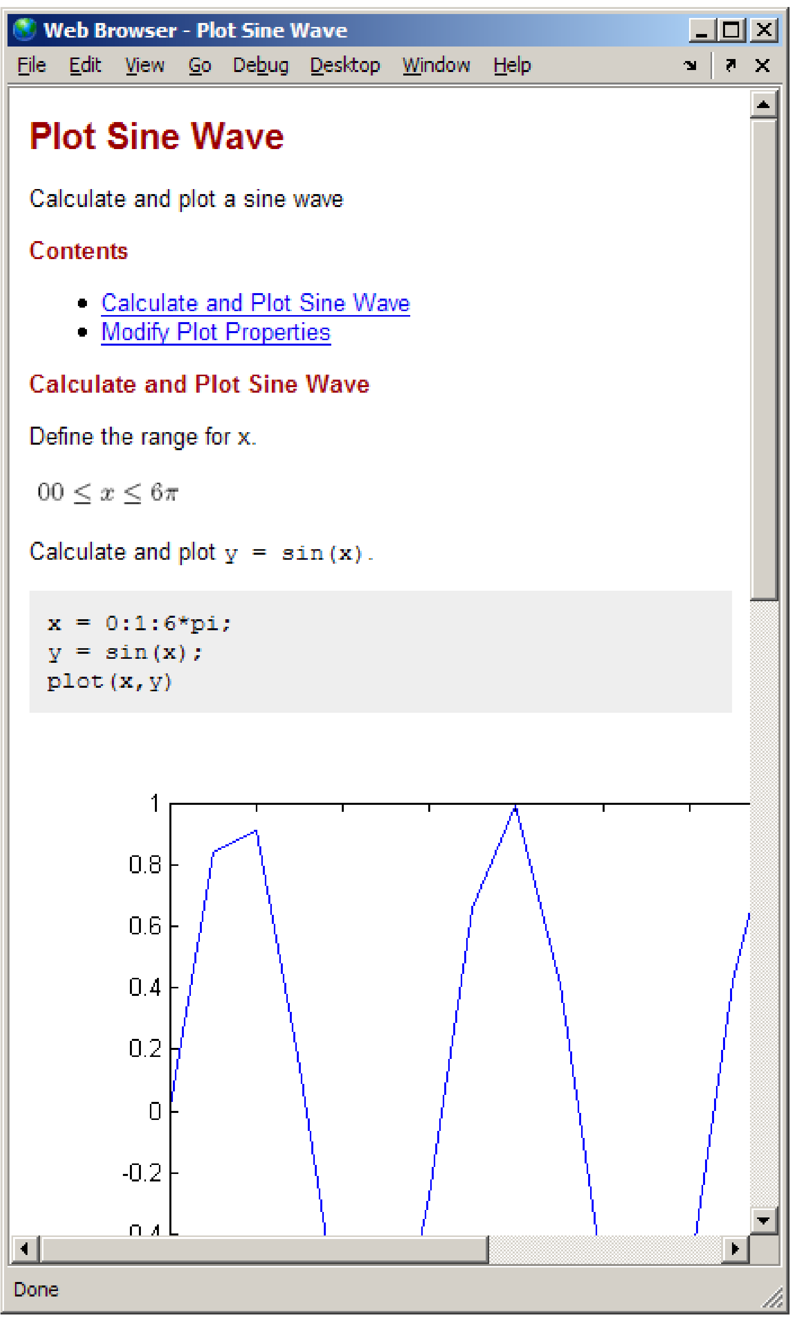
For More Information See "Editing and Debugging M-Files" as well as the function reference pages for `edit`, `type`, and the list of debug functions.

Publishing M-Files

While or after you create an M-file, you can use the Editor's **Cell > Insert Text Markup** menu options to specify the formatting you want for publishing the M-file to various output types. For example, you might want to publish an M-file to present it at a meeting, include it in a blog, or share it with colleagues.



After adding text markup, click the Publish button on the Editor toolbar. By default, MATLAB software generates formatted HTML output and presents the document in the MATLAB Web Browser.


Web Browser - Plot Sine Wave
File Edit View Go Debug Desktop Window Help
Plot Sine Wave
Calculate and plot a sine wave
Contents
Calculate and Plot Sine Wave
Modify Plot Properties
Calculate and Plot Sine Wave
Define the range for x.
00 ≤ x ≤ 6π
Calculate and plot y = sin(x).
x = 0:1:6*pi;
y = sin(x);
plot(x,y)
1
0.8
0.6
0.4
0.2
0
-0.2
Done

You can publish M-Files to HTML, XML, LaTeX, and PDF. If your system is a personal computer (PC), you also can publish M-Files to Microsoft Word and PowerPoint®.

For More Information See “Publishing M-Files” in the MATLAB Desktop Tools and Development Environment documentation, and the function reference pages for `publish`.

Improving and Tuning M-Files

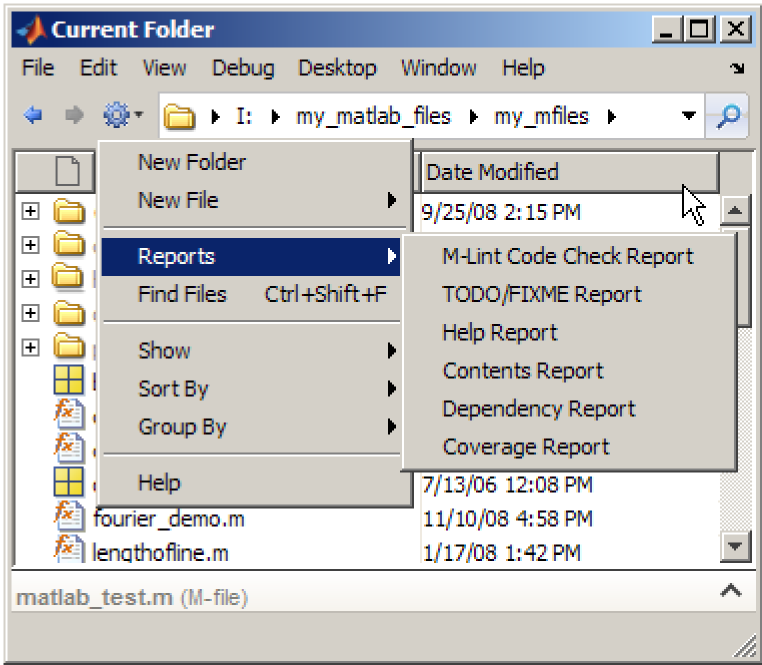
In this section...
“Finding Errors Using the M-Lint Code Check Report” on page 7-33
“Improving Performance Using the Profiler” on page 7-35

Finding Errors Using the M-Lint Code Check Report

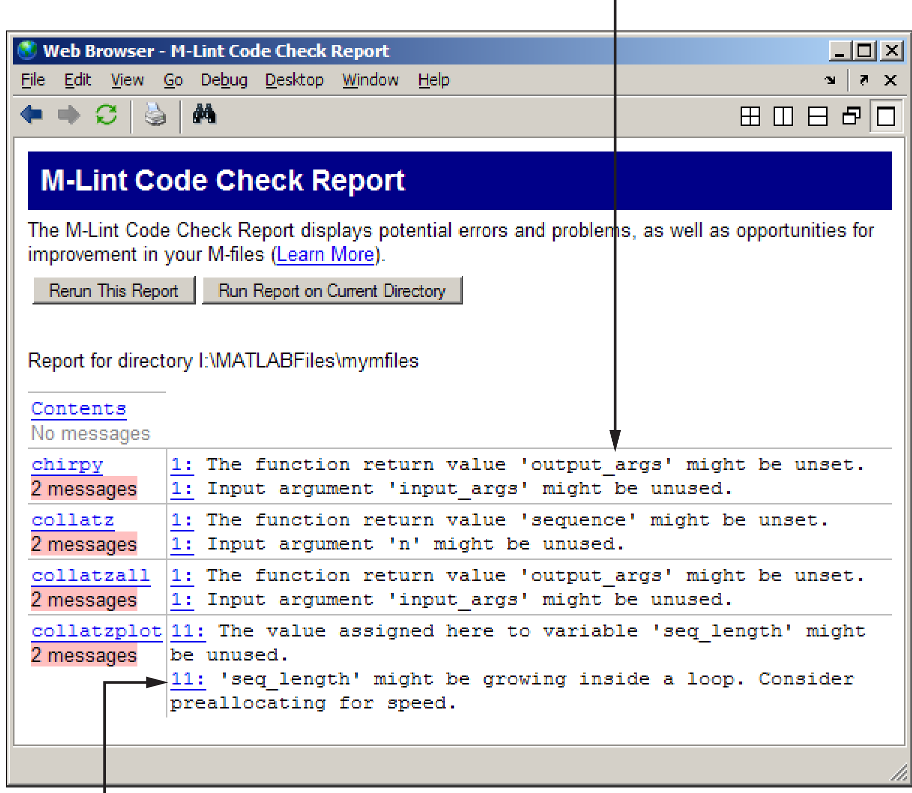
The M-Lint Code Check Report displays potential errors and problems, as well as opportunities for improvement in your M-files. The term *lint* is used by similar tools in other programming languages such as C.

Access the M-Lint Code Check Report and other reports from the Current Folder browser. From the Actions button, select **Reports**.

You run a report for all files in the current folder.



The M-Lint Code Check Report displays a message for each line of an M-file it determines might be improved. For example, a common M-Lint message is that a variable is defined but never used in the M-file.

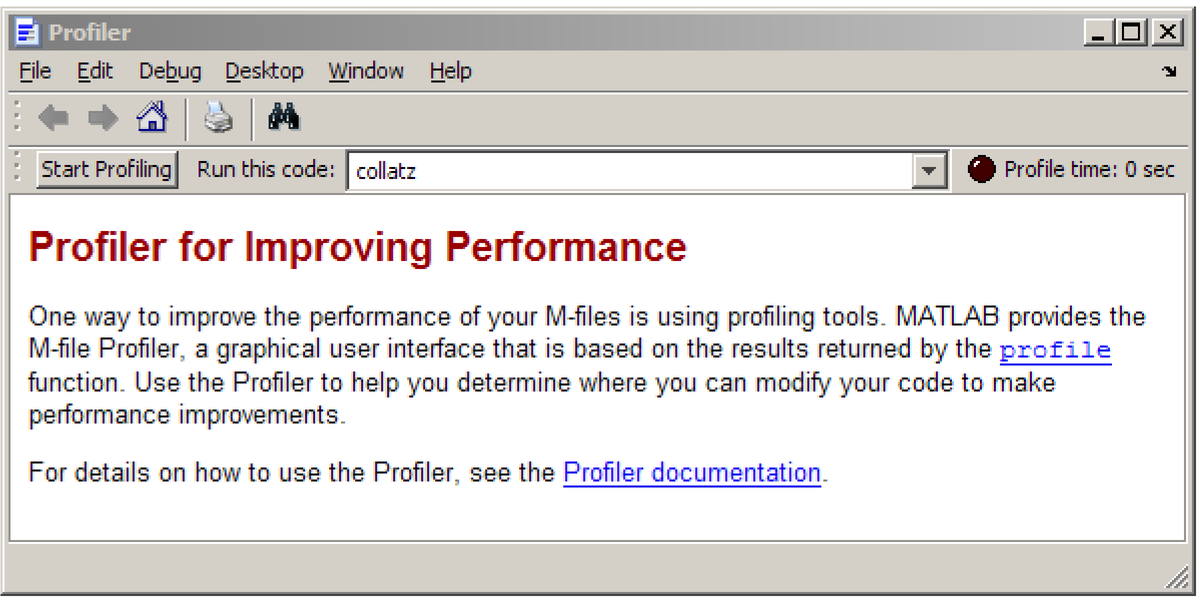


Alternatively, you can use automatic M-Lint code checking to view M-Lint messages while you work on a file in the Editor. You can also use the `mlint` function to get results for a single M-file.

For More Information See "Tuning and Managing M-Files" and "Checking M-File Code for Problems Using the M-Lint Code Analyzer" in the MATLAB Desktop Tools and Development Environment documentation, and the reference page for the `mlint` function.

Improving Performance Using the Profiler

The MATLAB Profiler helps you improve the performance of your M-files. Run a MATLAB statement or an M-file in the Profiler and it produces a report of where the time is being spent. Access the Profiler from the **Desktop** menu, or use the `profile` function.



For More Information See "Tuning and Managing M-Files" in the MATLAB Desktop Tools and Development Environment documentation, and the reference page for the `profile` function.

8

External Interfaces

Use MATLAB External Interfaces to connect MATLAB to programs, devices and data. Application developers use external interfaces to integrate MATLAB functionality with their applications. External interfaces also facilitate data collection, such as from peripheral devices like an oscilloscope or a remote network server.

- "Programming Interfaces" on page 8-2
- "Interface to .NET Framework" on page 8-4
- "Component Object Model Interface" on page 8-5
- "Web Services" on page 8-6
- "Serial Port Interface" on page 8-7

Programming Interfaces

In this section...

"Call MATLAB Software from C and Fortran Programs" on page 8-2
"Call C and Fortran Programs from MATLAB Command Line" on page 8-2
"Call Sun Java Commands from MATLAB Command Line" on page 8-3
"Call Functions in Shared Libraries" on page 8-3
"Import and Export Data" on page 8-3

Call MATLAB Software from C and Fortran Programs

Use the MATLAB engine library to call MATLAB from C and Fortran programs. When you call MATLAB from your own programs, MATLAB acts as a computation engine. For example, you can:

- Use MATLAB as a programmable mathematical subroutine library.
- Build an application with a front end (GUI) programmed in C and a back end (analysis) programmed in MATLAB.

Call C and Fortran Programs from MATLAB Command Line

Use MEX-files to call your own C or Fortran subroutines from the MATLAB command line as if they were built-in functions. For example, you can:

- Call preexisting C and Fortran programs from MATLAB without having to rewrite them as M-files.
- Code bottleneck computations that do not run fast enough in MATLAB in C or Fortran for efficiency.

The mxArray access library creates and manipulates MATLAB arrays. The mex library performs operations in the MATLAB environment.

Call Sun Java Commands from MATLAB Command Line

Every installation of MATLAB software includes Java Virtual Machine (JVM™) software. The JVM software allows you to use the MATLAB interpreter with Java commands and to create and access Java objects. For example, you can:

- Access Java API class packages that support I/O and networking.
- Access third-party Java classes.
- Construct Java objects in MATLAB.
- Call Java methods, using either Java or MATLAB syntax.
- Pass data between MATLAB variables and Java objects.

Call Functions in Shared Libraries

Use the MATLAB interface to generic DLLs to interact with functions in a dynamic link library (`.dll`) on Microsoft Windows platforms, a shared object file (`.so`) on The Open Group UNIX and Linus Tovald's Linux® platforms, or a dynamic shared library (`.dylib`) on Apple Macintosh platforms based on Intel® technology.

MATLAB supports any shared library written in C, or in any language that can provide a C interface.

Import and Export Data

MAT-files and the MAT-file access library provide a convenient mechanism for moving MATLAB binary data between platforms, and for importing and exporting data to stand-alone MATLAB applications.

Interface to .NET Framework

MATLAB provides an interface to the Microsoft .NET Framework which lets you leverage the capabilities of programming in .NET on the Microsoft Windows platform.

Component Object Model Interface

With Microsoft COM (Component Object Model) tools and technologies, you can integrate application-specific components from different vendors into your own applications. With COM, MATLAB software can include Microsoft® ActiveX® controls or OLE server processes, or you can configure MATLAB as a computational server controlled by your client application programs.

For example, you can:

- Include ActiveX® components, like a calendar, in your MATLAB program.
- Access existing applications that expose objects via Automation, like Microsoft® Excel®.
- Access MATLAB as an Automation server from an application written in Microsoft® Visual Basic® or C programming languages.

COM support in MATLAB is only available on the Microsoft Windows platform.

Web Services

Web services are XML-based technologies for making remote procedure calls over a network. They enable communication between applications running on disparate operating systems and development platforms. Web service technologies available in the MATLAB software are:

- Simple Object Access Protocol (SOAP)
- Web Services Description Language (WSDL)

Serial Port Interface

The MATLAB serial port interface provides direct access to peripheral devices that you connect to your computer's serial port, such as modems, printers, and scientific instruments. For example, you can perform the following tasks:

- Configure serial port communications.
- Use serial port control pins.
- Write and read data.
- Use events and callbacks.
- Record information to disk.

Index

Symbols and Numerics

: operator 2-8
2-D scatter plots
    getting started 5-14
3-D scatter plots
    getting started 5-16

A

algorithms
    vectorizing 4-31
annotating plots 3-23
ans function 2-5
application program interface (API) 1-4
array operators 2-24
arrays
    and matrices 2-24
    cell 4-11
    character 4-13
    columnwise organization 2-26
    creating in M-files 2-17
    deleting rows and columns 2-19
    elements 2-12
    generating with functions and operators 2-16
    listing contents 2-11
    loading from external data files 2-17
    multidimensional 4-9
    notation for elements 2-12
    preallocating 4-32
    structure 4-16
    variable names 2-11
arrow keys for editing commands 2-32
aspect ratio of axes 3-66
axes
    managing 3-66
    visibility 3-67
axis
    labels 3-67
    titles 3-67
axis function 3-66

B

bit map 3-81
break function 4-7
browser
    Help 7-8
built-in functions
    defined 2-14

C

callbacks 6-7
case function 4-4
catch function 4-7
cell arrays 4-11
char function 4-15
character arrays 4-13
characteristic polynomial 2-23
coefficient of determination
    described 5-16
colon operator 2-8
colormap 3-74
colors
    lines for plotting 3-58
Command History 7-6
command line
    editing 2-32
Command Window 7-5
complex numbers 2-12
    plotting 3-61
concatenation
    defined 2-18
    of strings 4-14
constants
    special 2-14
continue function 4-6
continuing statements on multiple lines 2-32
control keys for editing commands 2-32
correlation coefficient
    example using corrcoef 5-16
covariance

example using `cov` 5-15
current folder 7-21
Current Folder browser 7-22

D

data analysis
getting started 5-1
data source
for graphs 3-38
debugging M-files 7-27
deleting array elements 2-19
demos 7-7
running from the Start button 7-3
searching for 7-10
desktop
for MATLAB 1-7
tools 7-1
determinant of matrix 2-21
`diag` function 2-5
distribution modeling
getting started 5-11
documentation 7-7
searching 7-10

E

editing command lines 2-32
Editor 7-27 7-29
eigenvalue 2-22
eigenvector 2-22
elements of arrays 2-12
entering matrices 2-4
`eval` function 4-28
examples 7-7
executing MATLAB 1-7
exiting MATLAB 1-8
exporting graphs 3-52
expressions
evaluating 4-28
examples 2-15
using in MATLAB 2-11

F

`figure` function 3-63
figure tools 3-7
figure windows 3-63
with multiple plots 3-64
figures
adding and removing graphs 3-4
files
managing 7-21
filtering data
getting started 5-6
`find` function 2-28
finding object handles 3-92
`fliplr` function 2-7
floating-point numbers 2-12
flow control 4-2
folders
managing 7-21
`for` loop 4-5
format
of output display 2-30
`format` function 2-30
function functions 4-29
function handles
defined 4-28
using 4-30
`function` keyword 4-23
function M-files 4-20
naming 4-22
function of two variables 3-72
functions
built-in, defined 2-14
defined 4-22
how to find 2-13
running 7-5
variable number of arguments 4-23

G

global variables 4-26
graphical user interface
  creating 6-1
  laying out 6-3
  programming 6-7
graphics
  files 3-83
  Handle Graphics 3-85
  objects 3-86
  printing 3-82
grids 3-67
GUIDE 6-1

H

Handle Graphics 3-85
  defined 1-4
  finding handles 3-92
Help browser 7-7 to 7-8
  searching 7-10
help functions 7-7
highlighted search words 7-12
`hold` function 3-62

I

`if` function 4-2
images 3-80
imaginary numbers 2-12

K

keys for editing in Command Window 2-32

L

legend
  adding to plot 3-57
`legend` function 3-57
library
  mathematical function 1-3
lighting 3-76
limits
  axes 3-66
line continuation 2-32
line styles of plots 3-58
linear regression
  getting started 5-28
`load` function 2-17
loading arrays 2-17
local variables 4-23
log of functions used 7-6
logical vectors 2-27

M

M-files
  creating 4-20
  editing 7-27
  for creating arrays 2-17
  function 4-20
  publishing 7-29
  script 4-20
`magic` function 2-9
magic square 2-5
markers 3-59
MAT-file 3-80
mathematical functions
  library 1-3
  listing advanced 2-13
  listing elementary 2-13
  listing matrix 2-13
MATLAB
  application program interface 1-4
  desktop 1-7
  executing 1-7
  exiting 1-8
  history 1-2
  language 1-3
  mathematical function library 1-3

overview 1-2
quitting 1-8
running 1-7
shutting down 1-8
starting 1-7
matrices 2-20
creating 2-16
entering 2-4
matrix 2-2
antidiagonal 2-7
determinant 2-21
main diagonal 2-6
multiplication 2-21
singular 2-21
swapping columns 2-10
symmetric 2-20
transpose 2-5
measures of location
getting started 5-10
measures of scale
getting started 5-11
mesh plot 3-72
missing data
getting started 5-3
modeling data
getting started 5-27
multidimensional arrays 4-9
multiple data sets
plotting 3-57
multiple plots per figure 3-64
multivariate data
organizing 2-26

N

numbers 2-12
complex 2-12
floating-point 2-12

O

object oriented programming 4-33
object properties 3-88
objects
finding handles 3-92
graphics 3-86
online help 7-7
operators 2-13
colon 2-8
outliers
getting started 5-4
output
controlling format 2-30
suppressing 2-31
overlaying plots 3-62

P

path. *See* search path
periodogram 5-30
plot edit mode
description 3-23
`plot` function 3-56
Plot Selector tool
introduction to 3-15
plots
editing 3-23
plotting
adding legend 3-57
adding plots 3-62
basic 3-56
complex data 3-61
complex numbers 3-61
contours 3-62
editing 3-23
functions 3-56
line colors 3-58
line styles 3-58
lines and markers 3-59
mesh and surface 3-72

multiple data sets 3-57
multiple plots 3-64
overview 3-2
tools 3-10
polynomial regression
getting started 5-27
PostScript 3-83
preallocation 4-32
preprocessing data
getting started 5-3
present working directory. *See* current folder
presentation graphics 3-43
principal components 5-17
`print` function 3-82
print preview
using 3-48
printing
example 3-48
graphics 3-82
Profiler 7-35
Property Editor
interface 3-28
Property Inspector 3-25
using 3-25
publishing M-files 7-29

Q

quitting MATLAB 1-8

R

reference pages 7-10
release notes 7-10
`return` function 4-8
running
functions 7-5
MATLAB 1-7

S

scalar expansion 2-27
scatter plot arrays
getting started 5-18
scientific notation 2-12
script M-files 4-20
scripts 4-21
search path 7-21
searching
Help browser 7-10
semicolon to suppress output 2-31
shutting down MATLAB 1-8
singular matrix 2-21
smoothing data
getting started 5-6
special constants
infinity 2-14
not-a-number 2-14
specialized graphs 3-63
Start button 7-3
starting MATLAB 1-7
statements
continuing on multiple lines 2-32
executing 4-28
strings
concatenating 4-14
structures 4-16
`subplot` function 3-64
subscripting
with logical vectors 2-27
subscripts 2-7
`sum` function 2-5
summarizing data
getting started 5-10
suppressing output 2-31
surface plot 3-72
`switch` function 4-4
symmetric matrix 2-20

T

text
    entering in MATLAB 4-13
TIFF 3-83
title
    figure 3-67
toolboxes 1-3
tools in the desktop 7-1
`transpose` function 2-5
`try` function 4-7

U

`userpath` 7-21

V

Variable Editor 7-20
variables 2-11
    global 4-26
    local 4-23
vectorization 4-31
vectors 2-2
    logical 2-27
    preallocating 4-32
visibility of axes 3-67
visualizing data
    getting started 5-14

W

`while` loop 4-5
windows
    in MATLAB 1-7
windows for plotting 3-63
wireframe
    surface 3-72
working directory. *See* current folder
workspace 7-19
Workspace browser 7-19